

# UNIT COMMITMENT AND ECONOMIC DISPATCH IN MICRO GRIDS

*Despacho económico y de unidades en Micro Redes*

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**Abstract.-** As a result of the differences between classical large power grids and micro grids a new approach of the Unit Commitment (UC) and Economic Dispatch (ED) problem must be proposed. The high penetrations of renewable sources and distributed energy storage systems, as well as the possibility of working in a grid-connected or island mode are some of the main issues to cope with. Firstly the advantages and drawbacks of the use of the Lambda Iteration Algorithm (LIA) for solving de ED problem in a micro grid are discussed. In order to adapt the LIA to this context some modifications have been carried out. With regard to the Unit Commitment problem, a genetic algorithm with some novel specific operators has been designed. This algorithm is suitable to deal with different constraints and scenarios arising in a micro grid environment. In addition, a comparison between the different characteristics of the designed UC algorithm and the traditional Priority List (PL) method has been performed.

**Keywords:** micro grid; unit commitment; genetic algorithm; priority list; storage devices; renewable sources; distributed generation; lambda iteration algorithm.

**Resumen.-** *Producto de las diferencias existentes entre los sistemas tradicionales de generación y las micro redes (MR), el presente artículo propone un nuevo enfoque en lo que respecta la resolución de los problemas de Despacho Económico (DE) y de Unidades (DU). La fuerte presencia de energías renovables, la incorporación de sistemas de almacenamiento distribuidos y la posibilidad de que la micro red trabaje en isla o interconectada a la red principal son algunos de los aspectos a tener en cuenta a la hora de resolver dichos problemas. Primeramente se analizan las ventajas y desventajas del empleo del Algoritmo de Iteración Lambda (AIL) en la resolución de Despacho Económico, proponiéndose además modificaciones para adaptar el mismo al contexto de las micro redes. En lo que respecta a la resolución del despacho de unidades el artículo propone un algoritmo genético el cual emplea ciertos operadores que facilitan el tratamiento de las restricciones que surgen en este nuevo contexto. Finalmente se lleva a cabo una comparación entre el método de Lista de Prioridades (LP) y el algoritmo genético desarrollado.*

**Palabras clave:** *micro red; despacho de unidades; algoritmo genético; lista de prioridades; sistemas de almacenamiento; energías renovables; generación distribuida; algoritmo de iteración lambda.*

**1. Introduction.-** Recently the traditional energy network has been undergoing important changes. The centralized generation paradigm it is expected to be gradually replaced by the distributed generation (DG) model where micro grids (MG) play a key role. Benefits of DG include reliability enhancement, reduction of peak power requirements, improvement in power quality and provision of ancillary services [1] [2] [3]. A micro grid is a localized distributed

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network with sources and loads, which is capable of managing its own operation by an intelligent control system [4]. In addition, it has the ability to work in a grid-connected or island operation mode. Micro grids include several distributed generation sources such as diesel engines, micro turbines, wind turbines, photovoltaic panels, fuel cells, etc. In order to test the different technologies and develop better control systems a 300 kW micro grid will be installed at the technological park of San Sebastian [5].

The control system of the micro grid, which is briefly described next, is composed of several levels, namely: primary, secondary, tertiary and quaternary. Firstly, the quaternary control assigns the active and reactive power to each element of the grid according to the load demand. Based on this, the tertiary control fixes the voltages and frequencies references of the nodes whereas the secondary by means of a PI controller respond to the voltage and frequency deviations. Finally, the primary control employs a “droop control” to emulate the physic behavior of each element of the grid. This paper is exclusively focused on the quaternary control. The main functions executed in this level are the “Unit Commitment (UC)” and the “Economic Dispatch (ED)”. The UC problem consists in determining the startup and shut down schedule of units to meet the required demand [6]. Once the UC has taken place the Economic Dispatch is the responsible for allocating the system demand among the operating units while minimizing the generation cost. As a result of the differences between classical large power grids and micro grids new approaches of the Unit Commitment and Economic Dispatch problems must be developed [7] [8] [4]. The main differences between these two grid models are outlined next.

- Usually the penetration of renewable energy in micro grids is higher than in conventional grids. For that reason it is harder to forecast the maximum power output that the micro grid will be able to supply.
- As it has been mentioned, a micro grid can work either in interconnected or island mode. Moreover, if the micro grid is working in interconnected mode, it could sell or buy electricity to the main grid depending on the energy price.
- Although in large power grids it is possible to store energy, the main part of the power generated is instantly consumed. However, due to the reduced size of the micro grids a large proportion of the energy produced in it can be stored. The use of distributed storage systems in micro grids it is mainly motivated by the high penetration of renewable generation.
- Unlike what happens in micro grids, committing a unit in large power systems usually means bringing online a generator from several tens of kilowatts to few megawatts. This task entails much more difficulty and time that in the case of small generators. Furthermore, generators in micro grids have more flexible constraints in relation to the minimum time that a unit must be down or up. The MUT is the minimum time that a generator must remain “up” whereas the MDT refers to the minimum time that a generator must be shut down. These limits are fixed so as to avoid equipment fatigue and prevent excessive maintenance and repair cost due to the frequent unit cycling.
- Another difference between large power systems and micro grids is that in the latter case the number of generators involved may easily vary throughout the time. Since the search space grows exponentially with the number of units a UC algorithm that works well with a certain number of generators could have trouble with handling more units [8].

Summarizing, although the objectives of the Unit Commitment and the Economic Dispatch remains the same that in large power systems, the characteristics of a micro grid make it necessary to modifies the existing UC and ED algorithms.

## 2. Economic Dispatch

**2.1. Introduction.-** The ED problem is one of the most important optimization issues in power systems and it is closely related to the UC problem. Finding a bad solution for ED problem might also affect negatively the generation schedule. The objective of the Economic Dispatch is to

allocate the power demand among committed generators in the most economical manner while all physical constraints are satisfied. As long as the cost curve of each generator is convex, or what is the same, that it has a monotonically increasing incremental cost the ED problem can be easily solved [9] [10]. Methods such as the lambda iteration algorithm, gradient method or the Newton-Raphson are widely employed in solving the ED problem. Nevertheless, these techniques rely on the convexity assumption of cost curves and cannot handle the constraints imposed by some generators. In addition, the presence of restrictions such as ramp rate limits, valve points and prohibited operation zones introduces discontinuities that add additional complexity to the ED problem [11].

In order to deal with the non-convexities and discontinuities introduced by some generators, methods like dynamic programming, genetic algorithms [12], artificial intelligence and practical swarm optimization have been widely employed [13] [14]. Despite the existence of local minimums, these methods can find a solution close to the optimum in a reasonable period of time. Since the generators employed in the micro grids doesn't present non convexities, the Economic Dispatch will be solved by using the lambda iteration algorithm which is, so far, the most popular method for solving the ED problem [10]. However, the introduction of storage devices in the ED will make it necessary to perform some changes in the original lambda iteration algorithm.

**2.2. Lambda iteration algorithm.-** On the proposed method storage devices are treated as generators with constant incremental cost, which in turn, depends on the price of the kWh at the moment of being charged.

Unlike meta-heuristic methods the lambda iteration algorithm finds the global optimum of the ED problem. Nevertheless, the existence of units such as storage devices, with non-monotonically increasing incremental cost could lead to convergence problems.

Since the only units that don't meet this condition have a constant incremental cost, the convergence issue can be solved performing some changes on the original lambda iteration algorithm.

Briefly, the LIA consist on the followings steps [10]. Firstly two incremental cost values are fixed and the global power output of the micro grid that will meet these conditions is calculated. Then, the error associated to each incremental cost is determined as the difference between the power output of the micro grid and the power demand. Finally the next incremental cost is calculated interpolating or extrapolating the previous values. This process is repeated until the error associated to the solution is lower than a tolerance previously established. Figure 1 Shows the graphical solution to the economic dispatch problem for a set of three generators when the load demand is  $P_1+P_2+P_3$ .

At the beginning of the lambda iteration algorithm suitable initial incremental costs values must be chosen in order to assure the convergence. On the designed algorithm these values are set by means of the bisection method.

The non-convexity of the storage devices cost function has been tackled as follows. When dealing with such curves there can be an infinite number of possible power output associated to a specific incremental cost. To overcome this problem the power output of the micro grid is determined by fixing the power of the storage device firstly at its maximum and then at its minimum. If the power demand is between the power outputs values previously calculated, the LIA will not be able to solve the Economic Dispatch. In this case the storage device is pre-dispatched and not included in the LIA. Otherwise, convergence of the algorithm is assured without making any change.

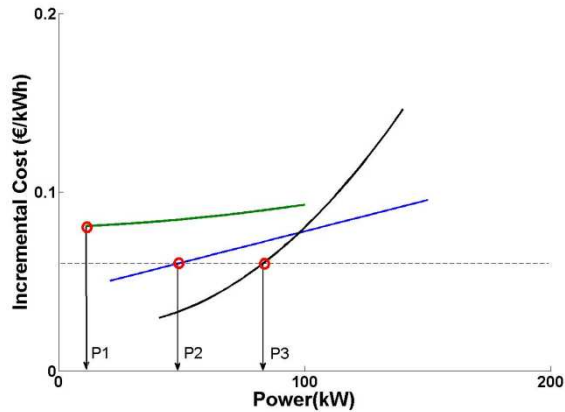


Figure 1.- Graphical solution to economic dispatch

### 3. Unit Commitment

**3.1. Introduction.-** The Unit Commitment problem in power systems is a mixed integer optimization problem. Its objective is to determine the optimum schedule of generating units while satisfying a set of system and units constraints. The major problem that arises in the resolution of the UC, is the high dimensionality of the possible solution space [6] [15]. Several methods have been developed so as to find a good solution in a reasonable period of time. Such methods include priority list, dynamic programming, Lagrangian relaxation, genetic algorithms [16] [17], simulated annealing, etc.

Nomenclature:

$CSC_i$	Cold startup cost of unit $i$
$F_i^t$	Generator fuel cost of unit $i$
HSC	Hot startup
$N$	Total number of generator units
$P_{i,min}$	Minimum real power generator of unit $i$
$P_{i,max}$	Maximum real power generation of unit $i$
$P_i^t$	Real power generation of unit $i$ at hour $t$
$P_D^t$	Load demand at hour $t$
$R^t$	Spinning reserve at hour $t$
$SD_i^t$	Shut-down cost of unit $i$ at hour $t$
$ST_i^t$	Startup cost of unit $i$ at hour $t$
$T$	Total number of hours
$T_{i,cold}$	Cold start hours of unit $i$
$T_{i,down}$	Minimum down time of unit $i$
$T_{i,up}$	Minimum up time of unit $i$
$T_{i,on}$	Time period during which unit $i$ is continuously “on”
$T_{i,off}$	Time period during which unit $i$ is continuously “off”
$U_i^t$	Status of the unit at hour $t$
$UR_i$	Ramp-up rate limit of unit $i$
$DR_i$	Ramp-down rate limit of unit $i$

SOC State of charge

In general the problem formulation of the Unit Commitment is given as follows [16] [15].

$$F(P_i^t, U_i^t) = \sum_{t=1}^T \sum_{i=1}^N F_i(P_i^t) + ST_i^t + SD_i^t \quad (1)$$

a) Power balance constraint

$$\sum_{i=1}^N P_i^t U_i^t = P_D^t \quad (2)$$

b) Spinning reserve constraint

$$\sum_{i=1}^N P_{i,max} U_i^t \geq P_D^t + R^t \quad (3)$$

c) Generator limit constraint

$$P_{i,min} U_i^t \leq P_i^t \leq P_{i,max} U_i^t, \quad i = 1, \dots, N \quad (4)$$

d) Minimum up and down constrain

$$U_i^t = \begin{cases} 1, & \text{if } T_{i,on} < T_{i,up} \\ 0, & \text{if } T_{i,off} < T_{i,down} \\ 0 \text{ or } 1 & \text{Otherwise} \end{cases} \quad (5)$$

e) Startup cost

$$ST_i^t = \begin{cases} HSC_i & \text{if } T_{i,off} \leq T_{i,cold} \\ CSC_i & \text{Otherwise} \end{cases} \quad (6)$$

f) Shut down cost

$$SD_i^t = \begin{cases} SD, & \text{if } U_i^{t-1} = 1 \text{ and } U_i^t = 0 \\ 0, & \text{Otherwise} \end{cases} \quad (7)$$

Ramp rate constraint for each unit

$$P_{i,min}^t \leq P_i^t \leq P_{i,max}^t \quad (8)$$

Where

$$P_{i,min}^t = \max(P_i^{t-1} - DR_i, P_{i,min}^t) \quad (9)$$

$$P_{i,max}^t = \min(P_i^{t-1} + UR_i, P_{i,max}^t) \quad (10)$$

g) SOC limits

$$SOC_{\min} \leq SOC \leq SOC_{\max} \quad (11)$$

**3.2. Priority list method.-** The Priority List (PL) method is the simplest way of tackling the Unit Commitment problem [18]. The method consists in assigning a priority to each unit according to specific criterions. These criterions are usually purely economic but they might also consider the fuel availability, or environmental issues. During the course of the day the units are started up or shut down depending on if this will leave enough generation to supply the load demand (3). Before taking a decision it is important to make sure that the remaining constraints are met. The main drawback of the Priority List method is that the solution obtained might not be close to the optimum, especially when dealing with a great number of generators [15].

Usually each unit has two possible states, encoded as follows: “1” if it is turned on and “0” if it is turned off. However, in a MG either the main grid or the storage devices might behave as a load. This will add complexity to the Unit Commitment problem increasing the number of possible solutions. From now on, when an element of the grid behave as a load its state will be encoded as “-1”.

The PL algorithm designed is composed of two main parts: at first the Unit Commitment problem is solved using the forecast demand and without considering the MUT and MDT constraints (5). Thereby it is possible to determine when it is strictly necessary to commit a unit. The storage devices are used so as to avoid or delay the startup of a predefined generator, being charged only if there is enough power available. On the other hand the main grid is regarded as a generator and has its own priority. However if it is previously specified, the micro grid will be able to sell energy to the main grid. The amount energy to sell depends on the power available. Once the generation schedule has been obtained using the forecasted demand, the definitive solution to the UC problem based on the real demand must be carried out. As stated previously, the main difference between the algorithms performed with the forecasted demand and with the real demand is that in the first case the MUT and MDT constraints are not taken in account. Having a generation schedule before executing the UC algorithm with the real demand, make it possible to know if a generator that is in condition to be shut down will be soon needed. Thus, the MDT constraints are always fulfilled.

In order to satisfy the spinning reserve constraint (3), a generator is shut down only if doing this will leave sufficient generation to supply the load plus the spinning reserve requirements. This is a valid procedure provided that the load demand and the generation capacity do not vary abruptly. Nevertheless, due to the small size of micro grids (in comparison with large power systems) and to the high penetration of renewable sources the load demand may undergo sudden changes. For this reason, in the designed PL algorithms the requirement of spinning reserve must be fulfilled during a certain period of time before shutting down a generator.

**3.3. Genetic algorithms.-** Genetic Algorithms (GAs) are general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings [19]. GAs encode the decision variables of a search problem into finite length strings of symbols ( preferably binary strings) .This strings which are candidate solution to the search problem are referred to as chromosomes while the specific sites of a chromosome are referred to as genes. For example, in the UC problem a chromosome represents the schedule of a specific generator, while the genes indicate the state of the unit. Unlike traditional search methods GAs rely on a population of candidate solution. In order to distinguish good candidates from the bad candidates a fitness function assigns a value to each solution. Following, the main steps of a GA are outlined [20].

1. Initialization. The initial population of candidate solutions is usually generated randomly across the search space. However, domain specific knowledge or other information can be easily incorporated.

2. Evaluation. Once the population is initialized or an offspring population is created the fitness values of the candidate solutions are evaluated.
3. Selection. Selection allocates more copies of those solutions with higher fitness values and thus imposes the survival of the fittest mechanism on the candidate solutions. The main idea of selection is to prefer better solutions to worse ones, and many selection procedures have been proposed to accomplish this idea.
4. Recombination. Recombination combines parts of two or more parental solutions to new possible better solutions. There are many ways of accomplishing this and competent performance depends on a properly designed recombination mechanism.
5. Mutation. While recombination operates on two or more parental chromosomes, mutation locally but randomly modifies a solution. There are many variations of mutations, but it usually involves one or more changes being made to an individual trait or traits.
6. Replacement. The offspring population created by selection, recombination and mutation replaces the original parental population.

The previous steps are repeated until a termination condition is reached. The Genetic Algorithm is finished after a pre-established number of iterations or when a solution satisfies specific criteria.

The proposed Genetic Algorithms has some special characteristics that enable to efficiently work in a micro grid context. A mutation that acts simultaneously in several gens and a repairing operator are the most novel features. The first step in designing a Genetic Algorithm is defining the encoding rules. The three possible states are encoded as “1”, “0” and “-1”. While “1” and “0” means that the unit is on or off, “-1” is reserved to represent the main grid or a storage device working as a load.

Usually initialization takes place randomly however in order to accelerate convergence the initial population will be generated as follows: when determining the states of the units at the  $j - th$  hour, the probability of reaching certain state will depend on the state of the unit at the  $(j - 1) - th$  hour. For each element of the micro grid it is necessary to define these probabilities in base of the MUT and MDT. The idea is to generate candidate solutions tending to meet the MUT and MDT constraints. The probability of reaching certain state will be expressed by a 3X3 matrix that will be called the probability matrix (PM). In addition this matrix could be also used to incorporate extra information about a specific problem. For instance, the element (3,2) of the PM will be set close to zero for a generator whose generation cost is very high (Table I).

State at $(j - 1) - th$ hour	-1	0	1
$P(state) _j = -1$	0	0	0
$P(state) _j = 0$	0	0.95	0.75
$P(state) _j = 1$	0	0.05	0.25

Table I.- Probability matrix example

Once the initial population has been created the fitness of each candidate solutions must be evaluate. The purpose of the Genetic Algorithm is to minimize the generation cost while satisfying a set of constraints. In micro grids where it is possible to store energy or work in interconnected mode with the main grid, the definition of “generation cost” is not evident. Firstly, the cost function of the storage devices will be analyzed. Unlike generators where the cost function depends on the characteristics of the unit and fuel price, the cost function of a storage device will depend on the price of the energy when being charged. From now on the cost rate of storage devices will be linearly modeled (12).

$$F(P) = a \cdot P \quad (12)$$

Where  $F(P)$  is the cost rate of the storage device in (€/h),  $P$  the power output in (kW), and  $a$  the incremental cost in (€/kWh). If the storage device has been charged from the instant  $t - 1$  to the instant  $t$ , the incremental cost varies as follows (13).

$$a|_t = \frac{SOC|_{t-1} \cdot a|_{t-1} + (SOC|_t - SOC|_{t-1}) \cdot EC|_{t-1}}{SOC|_t} \quad (13)$$

Where SOC is the state of charge, and  $EC$  is energy cost in (€/kWh) which is calculated by adding the per kilowatt-hour cost of each element of the grid whose state is “1” (generators, storage devices, main grid)

As stated previously, the generation cost must consider the price of the stored energy as well as the possibly of buying or selling energy to the main grid. Once the ED algorithm has been used to assign the power to each unit, the generation cost of the micro grid is calculated, as follows (14).

$$GC = [EC \cdot P_L - SEP \cdot P_{MG}] \cdot \Delta t + \sum_i ST_i^t + \sum_i SD_i^t + \sum_i PY_i \quad (14)$$

Where:

GC Generation cost in €

EC Energy cost in (€/kWh), which take into account all the elements whose state is “1”

$P_L$  Power consumed by the loads and the main grid

SEP Selling energy price in (€/kWh)

$P_{MG}$  Power consumed by the main grid

$\Delta t$  Period of time during which the generation cost must be evaluated

$PY_i$  Penalty applied when either MUT or MDT restriction is not fulfill

$SD_i^t$  Shut-down cost of unit  $i$  at hour  $t$

$ST_i^t$  Startup cost of unit  $i$  at hour  $t$

It is important to highlight the fact that  $P_L$  doesn't include the power consumed by the storage devices. Otherwise, the stored energy will be taken into account two times. Finally the diary generation cost is obtained by adding up the hourly generation cost. Furthermore, a fitness function has been designed in order to evaluate the quality of each solution candidate (15).

$$fit(GC) = \frac{1}{GC + \left( \frac{2(GC_M - GC_{Min})}{N-1} - GC_{Min} \right)} \quad (14)$$

Where:

$fit$  Fitness function

$GC_M$  Mean generation cost

$GC_{Min}$  Minimum generation cost

$N$  Parameter use to ponder de generation cost of each solution

After evaluating all the individuals of the population, the selection must be carried out. The method employed is known as “roulette-wheel” because each candidate is assigned a roulette wheel slot in proportion to its fitness. Thus, good solutions have a higher probability of being chosen than bad ones.



The next step is the recombination where some individuals are recombined in order to create a new offspring. This process also known as crossover consists on selecting randomly two individuals and recombining them with a probability  $P_R$ .

On the proposed Genetic Algorithm two different crossover operators have been employed: the one-point crossover and the two-point crossover (Figure II). In the first case a crossover site is selected at random over the string length and then the portions of the two strings beyond this crossover point are exchanged. In the two point crossover two sites are selected and the portions of string remaining between these points are exchanged.

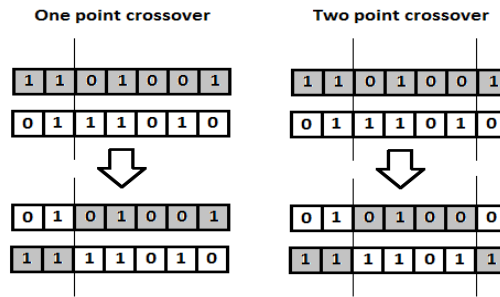


Figure II.- One point and two-point crossover

After performing crossover, strings are subjected to mutation in order to add diversity to the population and ensure that is possible to explore the entire search space. Two kinds of mutation operators have been employed, namely Mutation 1 and Mutation 2. The first one is a variation of the well-known “bit flip” mutation where each bit in a string is changed from 0 to 1 or *vice versa* with a probability  $P_{m1}$ . Due to the fact that storage devices and the main grid have three possible states the bit flip mutation had to be modified. In the case that a gen undergoes a mutation, its value will randomly change to one of the other two remaining options.

The second kind of mutation (Mutation 2) is a specific operator specially designed to deal with the Unit Commitment problem. Although the bit flip mutation introduces diversity on the population, the new individual will probably not fulfill the MUT or the MDT requirements. Unlike what happen in Mutation 1 where only one gen is modified, Mutation 2 affects a whole segment of the string. Each chromosome will be subjected to this operator with a probability  $P_{m2}$ . Firstly two sites, the starting and the end point, are selected at random over the whole length of the string. The idea is to delete and regenerate the segment of the chromosome between these two points. Then the gen corresponding to the starting point is subjected to the mutation. Its value is fixed as in the initialization, using the value of the gen of the previous hour and the Probability Matrix. This process is performed hour by hour until arriving to the end point.

Although the recombination and the mutation process generate new individuals the fulfillment of the constraints is not guaranteed. If a solution candidate that doesn't satisfy a specific requirement were discard and replaced by a new one there would be an important loss of information [20]. Hence, the need of designing an operator able to repair individuals that underwent either a recombination or a mutation.

The repair operator (RO) must be able to perform changes modifying as little as possible the original chromosomes. The first constraints to be evaluated are the minimum up and down times. The RO complete either with “0” or “1” the chromosomes whenever it is necessary without regarding the others constraints. Then the fulfillment of the SOC constraint is verified changing the states of the storage devices if necessary. Finally if the spinning reserve is lower than the requested value new units are committed. As in initialization and Mutation 2 this process takes place using the Probability Matrix. It is possible that during the previous step either a MUT or a MDT restriction has been violated. Nevertheless, if the chromosome is repaired again other constraint might be affected. Therefore, no further change will be made to the chromosomes.

Moreover, being flexible with the MUT and MDT constraints enables to examine zones of the search space that wouldn't have been explored otherwise.

Finally the offspring population created by selection, recombination and mutation replaces the original parental population. The previous steps are repeated until the termination condition is reached. During the evaluation process the best individual is stored so that it can be reintroduced on the next generation. Thereby, the convergence is accelerated and the information carried by the best individuals of each generation is never lost.

**4. Comparison between priority list and genetic algorithms.-** The priority list method is presented as a simple way of tackling one of the most challenging problems in power systems. PL algorithms can be easily programmed and are particularly suitable for dealing with UC problems involving few generators. Nevertheless as the number of variables increases, the PL method might have some trouble to find a good solution to the UC problem [15]. On the other hand GAs are characterized by exhaustively explore the search space, thereby ensuring the possibility of finding a close to the optimum solution. Although the benefits of employing GA are quite evident some drawbacks arise when designing the algorithm. Unless suitable genetic operators are employed the convergence to a good solution is not assured. Moreover it is essential to define several parameters such as population size, mutation and recombination probability, termination condition, fitness parameters, etc. This is not a simple task due to continuous trade-off between solution quality and execution time.

**5. Results.-** In order to test the performance of the designed algorithms several simulations have been carried out. The simulated micro grid consist of a diesel generator (DG), a micro turbine (MT), a battery bank (BB), wind turbines (WT) and photovoltaic panels (PVP). The cost rate of each generator has been modeled by a quadratic function. In addition, it has been taken into account that both the micro turbine and the diesel generator use the hot gases exhaust to produce useful thermal energy. The characteristics of each element of the grid are listed in Table II.

	MT	DG	PVP	WT	BB
P min (kW)	5	15	0	0	0
P Max (kW)	50	150	40	80	120
a (€/kWh <sup>2</sup> )	$15 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	0	0	0
b (€/kWh)	0,15	0,05	0	0	0
c (€/kWh)	2,62	0,6	0,32	0,15	a
Electric efficiency (%)	29	35	-	-	-
Thermal efficiency (%)	53	45	-	-	-
MUT (h)	1	3	0	0	0
MDT (h)	1	3	0	0	0
Startup cost (€)	2	5	0	0	0
SOC min	-	-	-	-	0,20
SOC max	-	-	-	-	0,80
Storage capacity (kWh)	-	-	-	-	350
Priority	2	3	1	1	3

Table II.- [20] [21] Units parameters

Note: Priority "1" is assigned to the generator with the highest priority

Figure shows the power output for the renewable sources which has been set based on weather forecasting

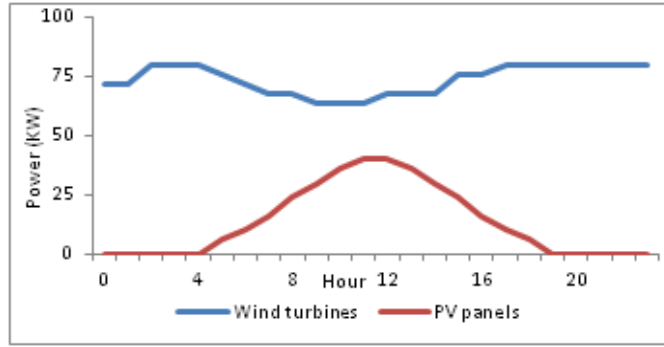


Figure III.- Predicted output of renewable sources

The proposed priority list method and genetic algorithm were tested both in island and interconnected mode. For the latter case the prices for buying or selling electricity have been set according to the hour (Table III).

	0hs-11hs	11 hs-21 hs	21 hs-24 hs
Buy electricity (€/ MWh)	12	80	13
Sell electricity (€/ MWh)	11	14	11

Table III.- Selling and buying electricity prices

The demand profile used in all the simulations is shown in Figure IV.

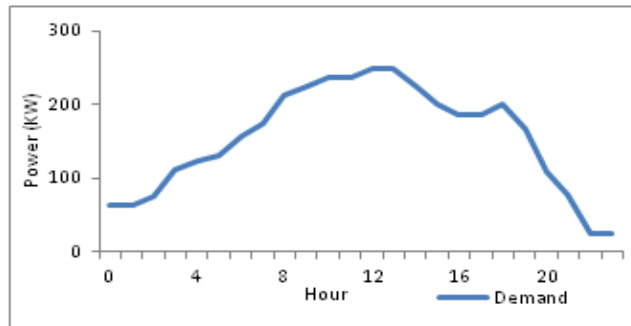


Figure IV.- Load demand profile

The main objective of the simulation is to compare efficacy and efficiency of the designed algorithms in different scenarios. To achieve this purpose the generation cost associated to each solution as well as the execution time of the algorithms have been contrasted. Both algorithms were coded in C language and the tests were conducted in a PC with a 2.80 Hz CPU and 1.0 GB Ram memory. The results obtained for the GA algorithm and the PL are respectively shown in Figure V and Figure VI It is possible to notice that GA manages the battery in a smarter way that the priority list method. In the former case the battery banks stores energy when the demand and the generation cost are low, using it latter during the peak hours. **¡Error! No se encuentra el origen de la referencia.** confirms what was expected. Either when working in interconnected mode or in island mode the solution found by the GA is significantly better. Nevertheless, the execution time of the priority list method is much lower than in the case of using a GA. Figure VII Shows the convergence process of a population of 200 individuals during 200 generations for the interconnected scenario.

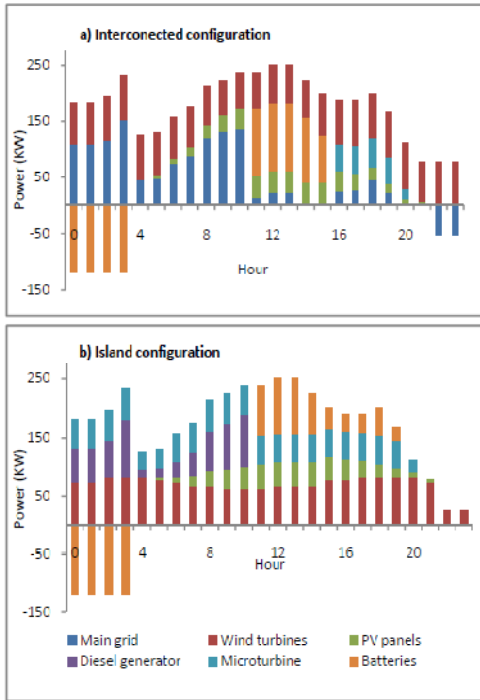


Figure V.- Generation schedules for a) interconnected and b) island configuration using the proposed GA

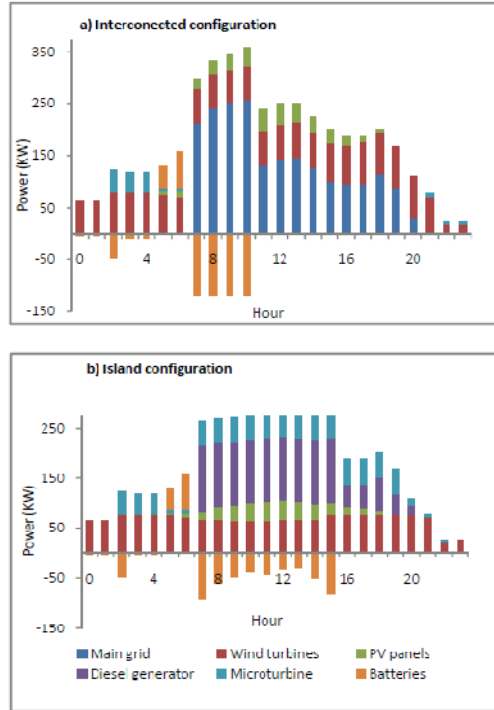


Figure VI.- Generation schedules for a) interconnected and b) island configuration using the proposed PL algorithm

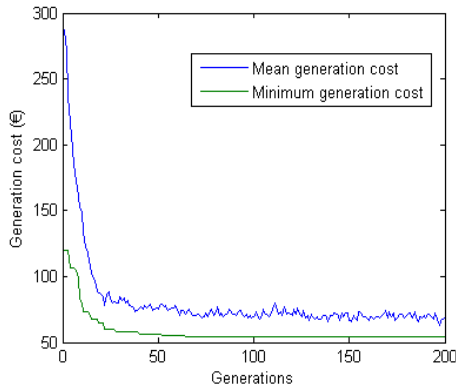


Figure VII.- Genetic algorithm convergence for the interconnected configuration

	Configuration	Generation cost (€)	Execution time (s)
PL	Island	352,5	0,7
GA	Island	211,8	97,7
PL	Interconnected	109,6	0,6
GA	Interconnected	54,6	83,8

Table IV.- Results for interconnected and island configuration

**6. Conclusions and future work.-** Both the Economic Dispatch and the Unit Commitment are essential problems to be solved in order to supply high-quality electric power to customers in a secured and economic manner. These two problems have been widely studied in the case of large power systems. Nevertheless, when working in a micro grid context some extra consideration must be taken into account. The high penetration of renewable energy sources, the large amount of energy that can be stored, the possibility of exchanging energy with the main grid as well as

the particular characteristics of generators, are the most remarkable issues to consider when working with micro grids

Firstly the lambda iteration algorithm has been modified so as to deal with no-convex cost function. Then two different methods of solving the UC problem, Priority List and Genetic algorithms have been analyzed. The proposed algorithms were finally tested in a micro grid context. The results arising from the simulations show that the solution obtained by means of the GA is significantly better than the one obtained using the Priority List method. Nevertheless, if the number of generators increases, the execution time of the GA could be a disadvantage. Further studies will be carried out in this regard. Future work will also include the use of meta-heuristic to solve de economic dispatch problem as well as optimal sizing of batteries banks.

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