Economic dispatch problem in smart grid system with considerations for pumped storage

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ABSTRACT

There are two significant issues with the incorporation of smart grid technology in power system operating studies including the economic emission, unit commitment problem (UCP). Economic dispatch problem (EDP) is a UCP sub-problem which find the optimum output for a given combination of running units. When using electro-energy systems to strategically distribute the power produced by all plants, the power economic dispatch problem is especially important. Pumped storage units that have the capacity to store energy can provide spinning reserves, which will lower overall costs and emissions. The general goal of this study is to develop control and optimization algorithms that are appropriate for managing new generation electrical networks. In this research work, the economic dispatch issue in a ten-unit smart grid system is resolved using the crow search algorithm (CSA), which acts as a local optimizer of the eagle strategy (ES). The outcomes of the ES-CSA program are compared to those found in the literature. The results of simulations suggest that adopting ES-CSA can lead to the generation of reliable and enough power that can meet the needs of both civil and industrial areas.

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1. INTRODUCTION

The energy sector occupies a strategic place in the world. The demand for energy, especially in the form of electricity, is constantly increasing. The traditional electricity network needs to be modernized, hence the need for the digitalization of the electricity network, which leads to what is now called the smart grid (SG). SG are a collection of technologies, ideas, and methods that make it possible to combine generation, transmission, distribution, and usage into a single network by utilizing cutting-edge sensor measurement, computer, information, control, and new energy technologies [1]. SG, on the other hand, employs digital technology to operate the grid and choose the best mode of power distribution in order to improve energy consumption, prices, dependability, and network transparency. As a result, the intelligent system will have a considerable impact on the power industry's finance and economics [2].

The economic dispatching problem is employed in the integrated planning system for electrical energy producing equipment. There have been some published solutions to the economic dispatching and ideal power flow problems. Researchers have provided some fixes for the economic dispatch problem (EDP) and optimal power flow (OPF) problems. Although it is restricted by the quadratic goal function, the direct method is precise and simple [3]. The economic dispatch problem is one of the power management approaches used to determine the actual power production of thermal producing units to meet the load demand (EDP). When using electro-energy systems to strategically distribute the electricity produced by all facilities, the economic dispatch problem of power is crucial [4].

The operation of electricity networks poses many technical and economic problems. The operation of the network must ensure the coverage of the required energy at all times and in all places, guarantee an acceptable quality of the delivered power and provide a high security of supply with the lowest possible cost. The emergence of the energy crisis and the increasingly expensive fuel prices have given the optimal or economical operation of electrical power systems an important position in the electricity industry. One of the fundamental problems is how to distribute the total load of the system over the available generation units in a way that minimizes the production cost. In light of these recommendations, the problem of economic dispatching is addressed.

In the early 1920's, economic dispatching was proposed as an approach to allocate the active power produced among the thermal units in the most economical way, taking into account the marginal costs of production and the losses of the network. Only the constraint of equality between generation and the sum of consumption-losses was kept, and the problem was treated as an active one. The transmission losses, which are approximately quadratic functions of the generated powers, are introduced as penalty factors in the cost function to be minimized. In order to solve these difficult and non-linear problems, we have proposed a metaheuristic approach, hybridizing the crow search algorithm with the eagle strategy (ES-CSA). The first part presents our contribution to the solution of the economic dispatching problem by the meta-heuristic optimization methods considered, namely the (ES), the (CSA), the (ES-CSA) [5]. The firewall operates in accordance with current security regulations. Given the current debates on passive defense and the significance of data security in smart grid systems, it is necessary to deploy additional security measures in addition to the firewall to increase the security of the smart grid system [6]. The remainder of this work is arranged in the following manner.

In section 2, the economic dispatch problem is discussed, and in section 3, the fundamentals of ES and CSA are briefly covered. The binary eagle strategy-based crow search algorithm is suggested in section 4 as a solution to EDP. The computational outcomes are presented in section 5. Section 6 concludes with outlining the conclusions.

2. ECONOMIC DISPATCH PROBLEM

The basic goal of dynamic economic dispatching is to determine the power contribution of each producing unit in the power system such that the total cost of generation is minimized for any load condition while keeping these generators' physical limits in mind. The total fuel cost of an electro-energy system with generation units is equal to the sum of the elementary fuel costs of the various units. In (1) and (2) provide the answer:

2.1. Economic dispatch problem–objective function

The total fuel cost of an electro-energy system with generation units is equal to the sum of the elementary fuel costs of the various units. In (1) and (2) provide the answer:

$$F_T0 = \sum_{i=1}^{NG} F_i(P_i) \qquad i = 1,2, \ldots., NG \tag{1}$$

$$F_T = \sum_{i=1}^{NG} a_i + b_i P_i + c_i P_i^2 \tag{2}$$

where P_i is the production of unit i (in MW); $F_i(P_i)$ is the production cost per unit i (in \$/h); a_i, b_i, c_i, $i = 1, \ldots, n$ are the coefficients of the cost function for each production unit i

The FT function is subject to the following constraints: production/demand balance constraint represented in (3), (4) represents the total transmission losses:

$$\sum_{i=1}^{NG} Pi = P_D + P_L \tag{3}$$

$$P_L = \sum_{i=1}^{NG} \sum_{j=1}^{NG} P_i B_{ij} P_j + \sum_{i=1}^{NG} B_{Oi} P_i + B_{OO} \tag{4}$$

where P_j is minimum power of unit j (MW); P^D is the demand (in MW); B_{ij} is element (i, j) of a square matrix of dimension (N × M); B_{oi} is element i of a vector of dimension N; B_{oo} is constant losses (MW).

The lower and upper limits of generator power are shown in (5), constraints on generator ramps in (6)-(8) represents the operating intervals for a thermal unit with prohibited operating zones [7]:

$$P_{i.min} \leq P_i \leq P_{i.max} \qquad i = 1,2, \ldots., NG \tag{5}$$

$$P_{i.t} - P_{i(t-1)} \leq UR_i \tag{6}$$

$$P_{i(t-1)} - P_{it} \leq DR_i \tag{7}$$

$$\begin{cases} P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi,1}^{L} \\ P_{Gi,k-1}^{u} \leq P_{Gi} \leq P_{Gi,k}^{L} \\ \vdots \\ P_{Gi,n_i}^{u} \leq P_{Gi} \leq P_{Gi}^{max} \end{cases} \quad k = 2, 3, \dots n_i \tag{8}$$

where ni is the number of prohibited areas in unit i, $P_{Gi,k}^{L}$et $P_{Gi,k}^{u}$ are, respectively, both the lower and upper bounds of the forbidden operation zone k.

2.2. Electric vehicles

With the development of associated technologies, electric vehicles may be able to sell electricity back to the grid. The system operator and a large number of electric vehicles (EV) owners are supposed to communicate through an aggregator [8]-[11]. If an EV remains idle for a length of time, its owner may enter into a load aggregation commitment agreement with the system operator. Plug-in (PEV) can be thought of as a unique unit when summed up. The marginal cost of involving more EV owners is rising, hence a quadratic function is assumed to represent the cost function of PEV.

$$\mathrm{f}\big(\mathrm{P}(\mathrm{m},\mathrm{t})\big) = \mathrm{a}(\mathrm{m})\mathrm{P}(\mathrm{m},\mathrm{t})^2 + \mathrm{b}(\mathrm{m})\mathrm{P}(\mathrm{m},\mathrm{t}) + \mathrm{c}(\mathrm{m}) \tag{9}$$

It's important to remember some basic restrictions. In the case of emergent use by EV owners, a lower state of charge (SoC) limit is first proposed (2). Second, a maximum cap on total EV output per hour should be established in order to guarantee the grid's secure operation (4). And last, since EVs could not always be connected to the grid, it is wise to set a time limit for when they are available to the system operator (5). Fourth, there is a maximum PEV capacity that can be used at any given hour.

$$\mathrm{SOC}(\mathrm{t},\mathrm{m}) \geq \mathrm{SOC}_{\mathrm{min}} \tag{10}$$

$$\mathrm{PEV}(\mathrm{t}) = \sum_{\mathrm{m}=1}^{\mathrm{M}} \mathrm{P}(\mathrm{t},\mathrm{m}) \leq \mathrm{PEV}_{\mathrm{max}} \tag{11}$$

2.3. Pumped storage

Pumped storage systems consume no fuel, hence their operation costs are negligible and are not considered in this analysis. However, the following prerequisites must be satisfied.
Lower and upper limits of generation:

$$0 \leq \mathrm{P_g}(\mathrm{m},\mathrm{t}) \leq \mathrm{P_{g-max}}(\mathrm{m}) \tag{12}$$

Lower and upper limits of pumping:

$$0 \leq \mathrm{P_p}(\mathrm{m},\mathrm{t}) \leq \mathrm{P_{p-max}}(\mathrm{m}) \tag{13}$$

Lower and upper limits of spinning reserve:

$$0 \leq \mathrm{P_{g-SR}}(\mathrm{m},\mathrm{t}) \leq \mathrm{P_{g-max}}(\mathrm{m}) \tag{14}$$

$$0 \leq \mathrm{P_{p-SR}}(\mathrm{m},\mathrm{t}) \leq \mathrm{P_p}(\mathrm{m},\mathrm{t}) \tag{15}$$

In a given hour, the sum of energy and spinning reserve must be less than P g-max (m):

$$\mathrm{P_g}(\mathrm{m},\mathrm{t}) + \mathrm{P_{g-SR}}(\mathrm{m},\mathrm{t}) \leq \mathrm{P_{g-max}}(\mathrm{m}) \tag{16}$$

Pumping and generating cannot happen at the same time in a pumped storage unit.

$$\mathrm{u_p}(\mathrm{m},\mathrm{t}) + \mathrm{u_g}(\mathrm{m},\mathrm{t}) \leq 1 \tag{17}$$

Energy storage balance for upper reservoir:

$$\mathrm{E}(\mathrm{m},\mathrm{t}) = \mathrm{E}(\mathrm{m},\mathrm{t}-1) - \mathrm{P_g}(\mathrm{m},\mathrm{t}) + \eta_{\mathrm{ps}}\mathrm{P_p}(\mathrm{m},\mathrm{t}) - \Big(\eta_{\mathrm{ps}}.\mathrm{P_{p-SR}}(\mathrm{m},\mathrm{t}) + \mathrm{P_{g-SR}}(\mathrm{m},\mathrm{t})\Big)\,\mathrm{re} \tag{18}$$

Energy storage limits for upper reservoir:

$$\mathrm{E_{min}}(\mathrm{m},\mathrm{t}) \leq \mathrm{E}(\mathrm{m},\mathrm{t}) \leq \mathrm{E_{max}}(\mathrm{m}) \tag{19}$$

Initial energy stored in upper reservoir:

$$E(m,T) = E(m,0) \tag{20}$$

Minimum energy stored in upper reservoir:

$$E_{min}(m,t) = E_{min}(m) + re(P_{p-SR}(m,t+1) + P_{g-SR}(m,t+1)) \tag{21}$$

3. OVERVIEW OF EAGLE STRATEGY AND CROW SEARCH ALGORITHM

3.1. Eagle strategy

A two-stage optimization approach called the Eagle strategy was introduced by [12]. This program imitates eagle behavior in the wild. In actuality, eagles look for their prey using two distinct methods. The first is a casual search conducted while flying, and the second is a focused hunt to capture prey when it is spotted. In this two-stage approach, the first stage employs a levy flight to investigate the global search space; if it finds a workable solution, the second stage does an intensive local search using a more potent local optimizer, such as hill-climbing and the down-hill simplex method. The two-stage process then restarts in a new location with new local search and new global exploration. The ability to utilize a parallel balance between a speedy local search and a sluggish global search is one of the key advantages of such a combination. There is another benefit, which is referred to as a methodology or strategy rather than an algorithm. In actuality, several algorithms can be applied at various points and stages throughout iterations. Algorithm 1 provides the essential steps of the ES.

```
Algorithm 1 Eagle strategy
Objective function f(x)
Initialization and random initial guess x^(t=0)
While (stop criterion) do
Global exploration by randomization (e; g; levy flights)
Evaluate the objectives and find a promising solution
Intensive local search via an efficient local optimizer
If (a better solution is found) then
Update the current best
End if
Update t=t+1
End while
```

3.2. Crow search algorithm

A new population-based stochastic search method called the CSA was just put forth by [13]. A recently created optimization method called the CSA is used to resolve challenging engineering optimization issues [14], [15]. It takes its cues from crows' perceptive behavior. The following is a list of the CSA's guiding principles [13]: i) crows live in the form of the flock, ii) crows memorize the position of their hiding places, iii) crows follow each other to commit thievery, and iv) crows protect their caches from being pilfered through probability.

Using the aforementioned premises as a guide, the CSA's central process consists of three fundamental phases: startup, generating a new position, and updating the crows' memory. The first population of crows represented by the n-dimensional representation is initially produced at random. The crow's position at iteration t is determined by $x^{i,t} = [x_1^{i,t}, x_2^{i,t}, \ldots\ldots, x_n^{i,t}]$ and it is presumed that this crow has committed to memory its best experience to date. $m^{i,t} = [m_{m1}^{i,t}, m_2^{i,t}, \ldots\ldots, m_n^{i,t}]$ Crow i randomly chooses a crow j from the population and tries to follow it to determine where its hiding place is in order to produce a new position (mj). In this scenario, two states are possible based on a metric called awareness probability (AP):

State 1: crow i is pursuing it, but crow j is unaware of it. As a result, the crow i will discover where the crow j is hidden.

State 2: crow j is aware that it is being followed. As a result, the crow j will deceive the crow i by moving to a different location inside the search region in order to prevent its cache from being stolen.

The position of the crows is updated in accordance with states 1 and 2 as (22):

$$x^{i,iter+1} = \begin{cases} x^{i,iter+1} + r_i \times fl^{i,iter} \times (m^{i,iter} - x^{i,iter}),, \\ r_j \geq AP^{j,iter} \text{A random positonofsearch spaceotherwise} \end{cases} \tag{22}$$

where $AP^{j,iter}$ stands for the awareness probability of crow j at iteration iter and rj is a uniformly distributed fuzzy number from [0; 1]. The ravens last memory update is as (23):

$$m^{i,iter+1} = \begin{cases} x^{i,iter+1}, & \text{if } f(x^{i,iter}) \text{is better than } f(m^{i,iter}) \\ & m^{i,iter}, \text{otherwise} \end{cases} \quad (23)$$

where f(-) stands for the value of the objective function. If the fitness function value of the new position is higher than the fitness function value of the memorized spot, a crow is observed to update its memory with the new position. The aforementioned procedure is repeated until an itermax termination requirement is satisfied. The ideal solution discovered by the CSA is finally returned as the best memory-based solution. In Algorithm 2, the CSA's primary steps are described.

```
Algorithm 2 Crow Search Algorithm
1:     Randomly initialize the position of a flock of (N_P) crows in the
            search space.
2:     Evaluate the position of the Crows
3:     Initialize the memory of each Crow
4:     While (iter≤ iter_max) do
5:     for i= 1: to N_P do
6:     Randomly choose one of the crows to follow (for example, j)
7:     Define an awareness probability
8:     if (r_j≥AP^(j, iter)) then
9:     x^(i, iter+1)=x^(i, iter)+r_i*fl^(i, iter)* (m^(j, iter)−x^(i, iter))
10:    else
11:    x^(i, iter+1)=a random position of search space.
12:      end if
13:    end for
14:    Check the feasibility of new positions
15:    Evaluate the new position of the Crows
16:    Update the memory of crows
17:    end while
```

4. BINARY EAGLE STARTEGY BASED CROW SEARCH ALGORITHM FOR UCP

In the first stage, the unit scheduling problem is optimized using the binary ES-CSA, and in the second step, the economic load dispatch problem is resolved using the Lambda-iteration approach [16]. Until the method satisfies the halting requirement, these two phases are repeated recursively. Unit scheduling's first subproblem is trickier to optimize than EDP's other subproblem. Therefore, the first sub-problem is the main topic of discussion in this work, and the second sub-problem is dealt with using the conventional Lambda-iteration method. The algorithm is iteratively optimized for these two subproblems until it satisfies the halting requirement. The following equations are used to convert (3) and (23) from continuous to binary space:

$$x^{i,iter} = \begin{cases} 1 & \text{if } s(x^{i,iter}) \geq rand(), \\ 0 & \text{if otherwise} \end{cases} \quad (24)$$

where $s(x^{i,iter})=\frac{1}{y}$, $y=1+e^{-x^{i,iter}}$ and rand() a number drawn at random from a uniform distribution [0; 1] and $x^{i,iter}$ reflects the revised binary position at iter iteration.

4.1. Solution representation and Initialization

The representation of a crow needs to be specified before the suggested binary ES-CSA can be used to solve EDP. An individual is another name for a crow. As a result, we designated each unit on/off (or 1/0) status as a gene. A sub-chromosome is made up of all the unit statuses that are available during a given hour, and an individual is made up of H sub-chromosomes throughout the time horizon H. Over the time horizon H, someone would show the unit commitment timetable. The units' onoff schedule is kept as an integer-matrix U with dimensions N G H. The following is an illustration of a population's individual shown as a matrix:

$$U = \begin{bmatrix} u_1^1 & u_1^2 & u_1^3 & \cdots & u_1^H \\ u_2^1 & u_2^2 & u_2^3 & & u_2^H \\ & \vdots & & \ddots & \vdots \\ u_N^1 & u_N^2 & u_N^3 & \cdots & u_N^H \end{bmatrix}$$

where uhi represents the unit's on/off status at time h (1=on, 0=off).

An initial collection of people is assembled during the initialization procedure. The candidate solution of each individual Uj; (j=1; 2; N P) is randomly initialized for the entire N P population. A uniform distributed random function is used to create either 0 or 1, with both outcomes having an equal chance of occurring, for the position uhi of each crow Uj.

4.2. Generate new solutions

As was already indicated, the ES is a two-stage method, and we can use different algorithms at different stages. Levy flights, a type of non-Gaussian stochastic process with step sizes distributed based on a Levy stable distribution, are used by ES to produce creative solutions in the initial stage. The next Levy flight is used whenever a new solution is created:

$$x^{i,iter+1} = x^{i,iter} + \alpha \oplus Levy(\lambda) \tag{25}$$

The step size that is pertinent to the problem's scales is shown here. Entry-wise multiplications are meant by the product. Levy flights effectively offer a random walk, with random steps chosen for large steps from a Levy distribution:

$$\mathrm{Levy}(\lambda) = \mathrm{u} = \mathrm{t}^{-\lambda},\ 1 \leq \lambda \leq 3 \tag{26}$$

The Mantegna algorithm [15], one of the most effective algorithms used to construct Levy flights, will be employed in this paper. Levy (λ)=s is assumed; hence the expression can also be explained as follows:
The step length s can be computed using Mantegna's technique [17] as (27):

$$\mathrm{x}^{\mathrm{i,iter+1}} = \mathrm{x}^{\mathrm{i,iter}} + \alpha \oplus \mathrm{s} \tag{27}$$

By using Mantegna’s algorithm [17], As shown in (28), the step length s can be determined:

$$\mathrm{s} = \frac{\mu}{|\mathrm{v}|} {}^{1}/_{\beta} \tag{28}$$

where μ and ν draw from the normal ditrutions respectively .that is : $\mu \sim \mathrm{N}(0, \sigma_u^2), \nu \sim \mathrm{N}(0, \sigma_\nu^2)$, and $\sigma_{v},\sigma_{u},$ are calculated as follows $\left(\frac{\Gamma(1+\beta).\sin(\frac{\pi\beta}{2})}{\Gamma\left(\frac{\beta+1}{2}\right).\beta.2^{(\frac{1-\beta}{2})}}\right)^{\frac{1}{\beta}}$, $\sigma_{v,} = 1$ Here $0 \leq \beta \leq 2$ and (:) is the Gamma function.

The second stage's intensive local search can be performed using the CSA. Although the CSA is a global search algorithm, it is simple to modify it to carry out an effective local search by restricting new solutions locally to the region with the best success rates. The CSA, as mentioned earlier, has two distinct parameters: flight length and AP (f l). While large values of AP produce a global search, small values of AP increase the local search. Thus, by lowering the awareness probability to very low values, the CSA can be simply exploited as a local optimizer. For optimal performance, we select the flight duration f 1=2. Results from this combination might be superior to those from CSA alone. In EDP, the unit status is represented by the binary integers 0 and 1. (i.e., OFF or ON). The suggested method must be modified in order to handle the binary variable (that is, 0 and 1) optimization problem because it is essentially a real-coded algorithm.

5. APPLICATION, RESULTS AND DISCUSSION

We discuss the outcomes of applying ES-CSA to the economic dispatch problem in this part, along with a comparison to the CSA [18] and ES [19] approaches. We constructed a 10-unit power unit system to put our theory about using ES-CSA to identify the system's ideal set of power generation to the test. The economic dispatch issue will be resolved in this study using the ES-CSA. The applications are written in the MATLAB 7.9 programming environment. At later iterations, convergence and the algorithm fled the local optima. It was shown that the ES-stochastic CSA's searching mechanism, which is based on gravitational forces between agents, is effective. Furthermore, the proposed mutation techniques boosted performance ES-CSA.

In both the best and average conditions, Figure 1 depicts the convergence of the ES-CSA based metaheuristic search process. To assess how our novel strategy differs from a widely used technique, we will contrast the manufacturing cost discovered by ES-CSA to that discovered by ES [20]. Now we'll look at the outcomes of using the eagle technique in conjunction with the Crow search algorithm to solve the economic dispatching problem of a 10-unit power production system (ES-CSA). A 10-node generating network is being considered [21]. While the 10-unit power system's loss coefficient matrix can be found in several works in the literature: The parameters of the proposed algorithm are given in Table 1. Table 2 shows the characteristics of the cost functions as well as the power limits of the 10 generators:

Table 1. Parameters of ES-CSA [22]

Algorithms/parameters	AP	Fl	β
CSA	0.2	2	-
ES-CSA	0.2	2	1.5

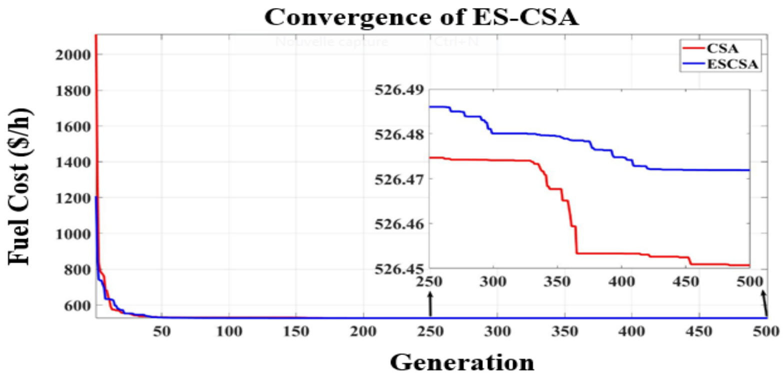

Figure 1. Convergence of ES-CSA system 10 unit

Table 2. Parameters of the cost function and the power limits of the ten generators

Unit	Pmax (MW)	Pmin (MW)	ai ($/MW2)	bi ($/MW)	ci ($)	di ($)	ei (MW-1)
1	55	10	0 .12951	40.54	1000	33 0.0174	33 0.0174
2	80	20	0 .10908	39.58	950	25 0.0178	25 0.0178
3	120	47	0.12511	36.51	900	32 0.0162	32 0.0162
4	130	20	0.12111	39.51	800	30 0.0168	30 0.0168
5	160	50	0.15247	38.53	756	30 0.0148	30 0.0148
6	240	70	0.10587	46.15	451	20 0.0163	20 0.0163
7	300	60	0.03546	38.30	1243	20 0.0152	20 0.0152
8	340	70	0.02803	40.39	1049	30 0.0128	30 0.0128
9	470	135	0.02111	36.32	1658	60 0.0136	60 0.0136
10	470	150	0.01799	38.27	1356	40 0.0141	40 0.0141

The loss coefficient matrix of the 10-unit power system:

$$B_{min} = 10^{-5}\begin{bmatrix} 4.9 & 1.4 & 1.5 & 1.5 & 1.6 & 1.7 & 1.7 & 1.8 & 1.9 & 2.0 \\ 1.4 & 4.5 & 1.6 & 1.6 & 1.7 & 1.5 & 1.5 & 1.6 & 1.8 & 1.8 \\ 1.5 & 1.6 & 3.9 & 1.0 & 1.2 & 1.2 & 1.4 & 1.4 & 1.6 & 1.6 \\ 1.5 & 1.6 & 1.0 & 4.0 & 1.4 & 1.0 & 1.1 & 1.2 & 1.4 & 1.5 \\ 1.6 & 1.7 & 1.2 & 1.4 & 3.5 & 1.1 & 1.3 & 1.3 & 1.5 & 1.6 \\ 1.7 & 1.5 & 1.2 & 1.0 & 1.1 & 3.6 & 1.2 & 1.2 & 1.4 & 1.5 \\ 1.7 & 1.5 & 1.4 & 1.1 & 1.3 & 1.2 & 3.8 & 1.6 & 1.8 & 1.8 \\ 1.8 & 1.6 & 1.4 & 1.2 & 1.3 & 1.2 & 1.6 & 4.0 & 1.5 & 1.6 \\ 1.9 & 1.8 & 1.6 & 1.4 & 1.5 & 1.4 & 1.6 & 1.5 & 4.2 & 1.9 \\ 2.0 & 1.8 & 1.6 & 1.5 & 1.6 & 1.5 & 1.8 & 1.6 & 1.9 & 4.4 \end{bmatrix}$$

5.1. Solution of the economic dispatching problem with piecewise quadratic fuel cost

In this case study, the same 10-unit test system is still taken into consideration, and the economic dispatch problem with piecewise quadratic fuel cost is solved using the ES-CSA approach. The issue is resolved for a load requirement of 2500 MW for comparison's sake. Losses of power are ignored. The CSA methods still yield fairly similar fuel consumption and production costs. One, two, or three different fuels can be used to power each unit. The Table 3 shows a comparison of the ideal fuel cost as determined by ES-CSA, CSA, and other algorithms. Figure 1 shows the rapid convergence of the proposed method to provide the load demand response solution with a fuel cost comparable to other methods discussed in the literature or even better.

Table 3. Results of the economic breakdown of the 10-unit system

P (MW)	MPSO [23]	HGA [24]	ARCGA [25]	CSA	ES-CSA
P1	206.5	206.5422	207.297	206.5190	206.5190
P2	206.5	206.4582	206.5129	206.4573	206.4573
P3	265.7	265.7636	267.5501	265.7391	265.7391
P4	236.0	235.9436	235.877	235.9531	235.9531
P5	258.0	257.9942	258.7206	258.0177	258.0177
P6	236.0	235.9546	235.3396	235.9531	235.9531
P7	268.9	268.8709	268.8669	268.8635	268.8635
P8	235.9	235.9425	235.7427	235.9531	235.9531
P9	331.5	331.4712	330.3599	331.4877	331.4877
P10	255.1	255.0589	253.7333	255.0562	255.0562
Fuel cost ($/h)	526.239	526.240	526.259	526. 2377	526.2388

6. CONCLUSION

With respect for pumped storage as an energy storage system, we studied and modelled the restrictions associated with the issue of the best distribution of electrical power, which is known as an economic dispatching problem for a smart grid. The eagle strategy, combined with the crow search algorithm, has been proposed to solve this combinatorial optimization problem of non linear characteristics. The performance of the proposed metaheuristic ES-CSA was tested for a benchmark case with 10 generators. The ES-CSA method was able to handle the nonlinearity of the EDP problem. The (ES-CSA) method's outcome decreased the cost of the generated power and the overall transmission power loss. The simulation results show that the proposed ES-CSA strategy is significantly better than other algorithms dealing with the same type of problem, namely CSA, ARCGA, HGA and MPSO in terms of solution quality. For future works, we suggest to hybrid wind and solar thermal systems in smart grid environment.

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