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APPLICATION OF A NEW HYBRIDIZATION TO SOLVE ECONOMIC DISPATCH PROBLEM ON AN ALGERIAN POWER SYSTEM WITHOUT OR WITH CONNECTION TO A RENEWABLE ENERGY

Abdelkader Si TAYEB [1,2*], Benyekhlef LAROUCI [3], Daoud REZZAK [1], Yehya HOUAM [1], Hamid BOUZEBOUDJA [2], Abdelhak BOUCHAKOUR [1]

[1] Unité de Recherche Appliquée en Energies Renouvelables, URAER, Centre de Développement des Energies Renouvelables, CDER, 47133, Ghardaïa, Alegria. si_tayeb12@yahoo.fr
[2] Faculty of electrical engineering, USTO-MB. B.P 1505 El M'naouar, Oran, 31000, Algeria, Laboratory of Sustainable Development of Electrical Energy LDDEE
[3] Department of Electrical Engineering, Faculty of Applied Sciences, University Kasdi Merbah Ouargla, Street Ghardaia, 30000, Ouargla, Algeria

Abstract

The most important contribution of this article is the use of four metaheuristic approaches to tackle the problem of economic dispatching, with the goal to study the influence of the injection of a renewable energy source on the electricity cost in the Algerian network, and minimizing the production cost of electrical energy while accounting for transmission losses.

A Genetic Algorithm (GA) (a real coding) and Egyptian Vulture Optimization Algorithm (EVOA), as well as two hybridizations between the metaheuristics: Classic and Modern hybridization (C.H.GA-EVOA, M.H.GA-EVOA), are presented in this work. These techniques are used to address optimization difficulties of two Algerian electricity networks. The first has three system units, whereas the second has fifteen system units. The second electricity network is connected to a solar energy source.

The findings obtained are compared with other techniques to validate the high performance of the suggested methods for addressing the economic dispatch issue. This study demonstrates that EVOA and C.H.GA-EVOA provide trustworthy results, and that M.H.GA-EVOA surpasses them.

Keywords: economic dispatching; Genetic Algorithm; Egyptian Vulture; Classic Hybridization; Modern Hybridization; solar energy.

1. INTRODUCTION

Electrical energy consumption is increasing rapidly, with global consumption having doubled on average over the last 10 years from the beginning of the nineteenth century. This has resulted in an increase in the length and complexity of electrical networks, forcing researchers in this sector to select the best feasible solutions [1-5].

To ensure that the network runs smoothly, we must address economic dispatch issues, which necessitate improving electrical energy management by lowering production costs while maintaining a balance between production and consumption [6-10].

Researchers are continuously creating algorithms that make it possible to program the production of power plants in an optimal method in order to fulfill these goals in the energy industry. Among these algorithms (CBA) chaotic bat algorithm [11] and (CSA) cuckooo search algorithm [12, 13], (PSO) particle swarm optimization, (CTLBO) chaotic teaching learning-based optimization [14], (KGMO) kinetic gas molecule optimization algorithm [15], (THS) tournament-based harmony search [16], (IA) Immune Algorithm [17], (SOA) seeker optimization algorithm [18], (MGSO) modified group search optimizer [19], (MSOS) modified symbiotic organisms search [20], (GWO) grey wolf optimization [21], (HGWO) hybrid grey wolf optimizer [22], (CSO) crisscross optimization algorithm [23], (GA) genetic algorithm [24], and (MABC) modified artificial bee colony algorithm [25]. Some of these algorithms are based on mathematical optimization methods witch are continually improved in order to increase their performance so that they are exploited instantaneously at the dispatching level. In parallel, another family of methods based on linear programming and nonlinear programming has appeared [26].

The danger of convergence towards a local optimum is a drawback of these approaches, especially if the goal function is non-linear or the derivatives are difficult to compute.

In combinatorial optimization, many problems are often difficult to resolve in a manner that is accurate [27]. This is not due to a lack of mathematical knowledge, but rather to technical problems. So against these obstacles, it must resort to methods of approximation of the solution. We will not seek more to obtain necessarily the best solution but rather a solution of good quality obtained to reduce loses and cost [28-32].

We proposed the use of two original stochastic optimization methods, the Genetic Algorithms GA and the Egyptian Vulture Optimization Algorithm EVOA, as well as two hybridizations: Classic Hybridization (C.H.GA-EVOA) and Modern Hybridization (C.H.GA-EVOA) to overcome the complexity of the problem of adaptation and to reduce costs and losses (M.H.GA-EVOA).

This study suggested a novel hybridization of GA and EVOA that uses metaheuristics of combinatorial optimization to solve the problem of the optimal allocation of active powers in two Algerian electricity networks with/without connection to solar energy production units.

For the first time, we use the EVOA, a metaheuristic approach of combinatorial optimization, to reduce the cost of producing electrical energy.

Then, with the aid of Genetic Algorithms, we apply a second technique of artificial intelligence to minimize the cost of producing electrical energy by binary encoding and then Natural by actual coding. Then we will build hybridization between: a GA and an EVOA method witch exhibited robustness, accuracy, highest performance, high precision, high stability, and simplicity.

- The first direct hybrid algorithm is a direct combination of GA and the EVOA method. In a first phase the GA explore the research space with the aim of discovering sub-spaces and providing a coarse solution, namely a solution located inside the basin of attraction of the global minimum. In a second phase, EVOA uses the best solution provided by the GA as initial estimate and continues the search according to its own mode of exploitation; it is the classic hybridization (C.H.GA-EVOA)
- The second hybrid algorithm in a first phase, the GA and the EVOA explore in parallel the research space with the aim of discovering promoter subspaces and providing coarse solutions, namely solutions located within the attraction basin of the global minimum. In a second phase, EVOA and GA use the best solution provided by the two algorithms as initial estimates and continue the search according to its own mode of operation. This principle is repeated for all the number of iterations, it is the modern hybridization (M.H.GA-EVOA).

The proposed approach has been tested on a variety of test systems, including two Algerian electricity networks, the first of which has three system units and the second of which has fifteen. The second Algerian electricity network has been optimized without and with connection to a solar energy source, with simulation results obtained in MATLAB. The results show that genetic algorithms, EVOA, classic and current hybridization have a clear interest in achieving dependable convergence to a global optimum while minimizing overall costs.

Compared with other methods, the results obtained are better in terms of minimizing the cost function.

2. PRINCIPLE OF ECONOMIC DISTRIBUTION OF POWERS

The basic goal of economic dispatch is to determine the active power contribution from each group of the electrical system's output such that the overall cost of production is reduced for any load state. The cost of manufacturing a unit varies depending on the amount of electricity it produces.

The overall cost of the fuel in an electro-energy system with multiple producing units is simply equal to the sum of the fuel costs of the various units, or:

We consider a production-transport network at n node where we have ng unit nodes. The function of this network's total production cost is given by the following form. [8], [11], [14]:

$$F_{glob} = \sum_{i=1}^{ng} F_i\left(P_{gi}\right) \quad (1)$$

With:

P_{gi}: Represents the active powers generated.

ng: Represents the number of nodes generators.

F_i (P_{gi}): Represents the cost of production of the unit i.

F_{glob}: Represents the sum of the functions of the cost of each unit.

The problem of the economic distribution of powers is to minimize the function of the total cost of fuel necessary for the production of energy requested.

This function is given by a polynomial of degree (n) in the following general form:

$$F\left(P_g\right) = a_0 + a_1 P g + a_2 P_g^2 + ... + a_n P_g^n \quad (2)$$

The coefficients of the latter are computed using one of the interpolation methods, although in reality, this equation takes the form of a second-degree polynomial, i.e.

$$F_i\left(P_{gi}\right) = c_i + b_i P_{gi} + a_i P_{gi}^2 \text{..................} i = 1,....,ng \quad (3)$$

a_i, b_i, c_i: Represents the coefficients of the cost function specific to the unit (i) [12], [25]. It is therefore, at this stage that the problem of the optimal allocation of powers arises, it can be represented as follows**:**

It is necessary to minimize the cost of electrical energy for the whole of units:

$$\text{Min}\left\{F_{\text{glob}}\left(P_{\text{gi}}\right)=\sum_{\text{i}=1}^{\text{ng}}F_{\text{i}}\left(P_{\text{gi}}\right)\right\} \quad (4)$$

Under the following constraints:

Equality constraints

$$\sum_{\text{i}=1}^{\text{ng}}P_{\text{gi}}=\sum_{i=1}^{ng}P_{\text{D}}+P_{\text{L}} \quad (5)$$

The constraints of inequality

$$P_{gi}^{\min}\leq P_{gi}\leq P_{gi}^{\max} \quad (6)$$

with:
n: Total number of nodes.
P_{gi}: Active power produced by the ith unit node.
P_{D}: Active power consumed by ith load.
P_{L}: Losses total active in the network.
$P_{gi}^{\max}$: Maximum active power produced by ith unit.
$P_{gi}^{\min}$: Minimum active power produced by ith unit.
where P_{D} is the total power demand (system load) and P_{L} is the total transmission loss.

The exact value of the transmission losses can only be obtained from a study of the power flow. Nevertheless, in studies of the economic dispatching, transmission losses are often expressed as a function of the active powers generated. This technique is commonly referred to as the *B* coefficient method. In this approach, the losses are approximated by the Kron formula [30].

$$P_{\text{L}}=\sum_{\text{i}=1}^{\text{N}}\sum_{\text{j}=1}^{\text{N}}p_{\text{i}}B_{\text{ij}}p_{\text{j}} \quad (7)$$

where the terms B_{ij} are called coefficients of losses or coefficients *B*. The coefficients of the losses are not constant, but vary according to the operating conditions of the system. However, acceptable results can be obtained if the current operating conditions are relatively close to those for which the coefficients *B* have been calculated [5].

3. USED METAHEURISTICS METHODS

3.1 Description of EVOA

The Egyptian vulture's optimization is based on the behavior of Egyptian vultures in quest of food, when they choose stones and hurl them with a probabilistic force and angle to break the eggs of other birds. The probabilistic decision that an Egyptian vulture singer makes to pick solutions evolves continually as the choice of stones, force, and angles of throwing stones changes [33].

This technique offered a combinatorial stochastic optimization strategy and demonstrated the speed of a novel method for finding acceptable solutions while avoiding premature convergences.
This method is versatile (it can be applied to similar versions of the same problem), robust and of course based on a population of individuals.

The EVOA algorithm is started with a random population of potential solutions, which are regarded as starting answers to the issues of food search in the search space. Each initial solution is drawn to its best choice discovery in the past, as well as the best decision discovery by its Neighborhood's first solutions. The EVOA algorithm has numerous adjustment factors that control the number of beginning values, the size of neighborhoods, and the precision with which the neighborhoods are created [34].

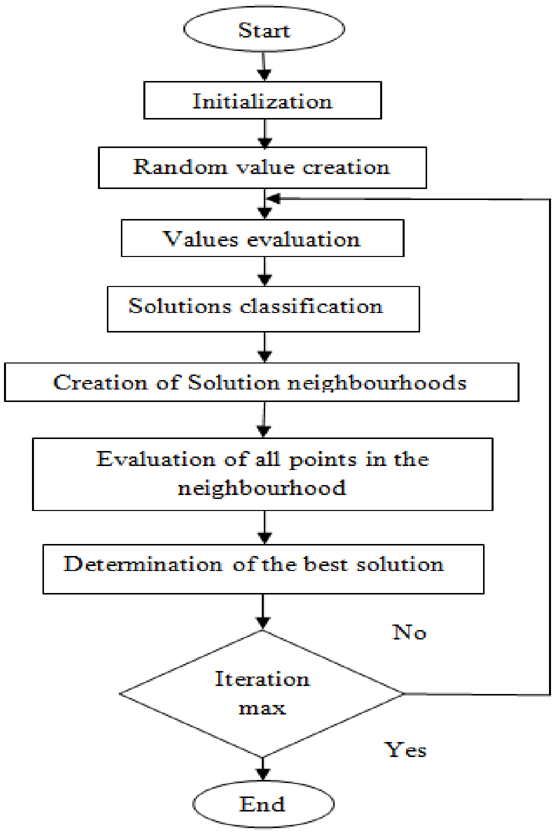

Fig.1. EVOA's organizational chart.

3.2 Genetic Algorithms

Genetic Algorithms, try to simulate the evolution process of a population. It part of a population N solutions of the problem presented by individuals. This population randomly chosen is called Initial. The adaptation degree of an individual to the environment is expressed by the value of the cost Function (Function Objective) f(x), or x is the solution that the individual represents.

It is said that an individual is much better adapted to its environment, when the cost of the solution that it represents is more low Within this population, then intervenes the random selection of one or two parents, who produce a new solution (new population), through the genetic operators, such that the crossing and the mutation. By iterating, this process produces a population, richer in individuals who are better adapted [35,36].

3.3 The hybrid algorithms

The most productive way of hybridization appears to be the mix of neighborhood methods [37], evolutionary approaches, and other methods. The basic concept behind this hybridization is to take advantage of the strength of neighborhood search and evolutionary algorithm recombination on a population of solutions. Without a doubt, hybrid algorithms are among the most effective approaches [38].

3.3.1 Working principle of proposed hybridizations

Classic hybridization (C.H.GA-EVOA)

The first direct hybrid algorithm is a direct combination of GA and the EVOA method. In a first phase the GA explore the research space with the aim of discovering sub-spaces and providing a coarse global solution, namely a solution located inside the basin of attraction of the global minimum [39]. In a second phase, EVOA uses the best solution provided by the GA as initial estimate and continues the search according to its own mode of exploitation. This combination of GA and EVOA is proposed to solve problems of creation of values initials, and to reduce computation time [40].

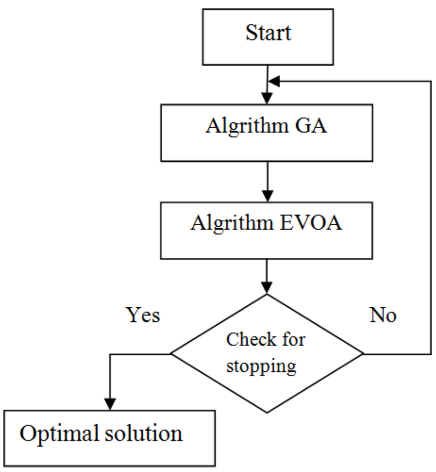

Fig. 2. Diagram representing classic hybridization (C.H.GA-EVOA) of GA and EVOA.

Modern hybridization (M.H.GA-EVOA)

The second hybrid algorithm, first, the GA and the EVOA explore in parallel the research space with the aim of discovering promoter subspaces and providing coarse solutions, namely solutions located within the attraction basin of the global minimum. In a second phase, EVOA and GA use the best solution as initial estimates and continue the search according to its own mode of operation. This principle is repeated for all the number of iterations, it is the modern hybridization (M.H.GA-EVOA).Therefore, this hybrid method, such as the combination of two methods, have been proposed to eliminate each method's drawback and Weak point

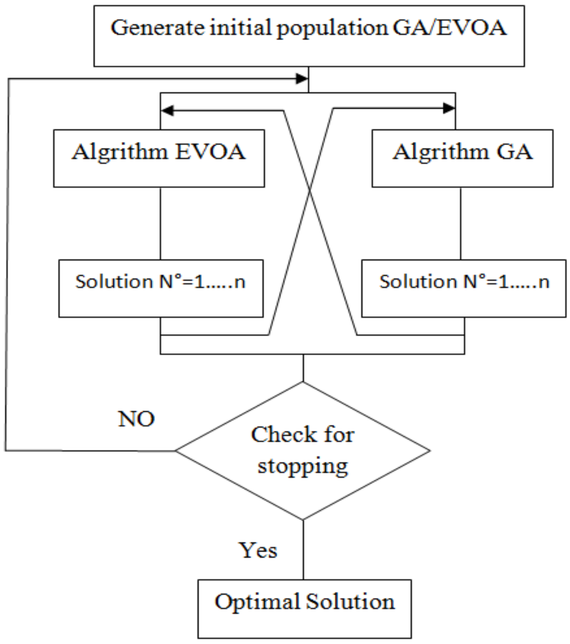

Fig. 3. Diagram representing modern hybridization (M.H.GA-EVOA) of GA and EVOA.

3 RESULTS AND DISCUSSION

Application 1: **A- electrical network without solar energy production** unit

The Algerian West 220 kV network was used to test the system. Figure 4 shows a single-line schematic of the system. The system is made up of 14 nodes, including three generators: the "Mersa El Hadjadj" power plant (node 1), the "White Ravine" power plant (node 4) and the "Tiaret" unit (node 3) [41].

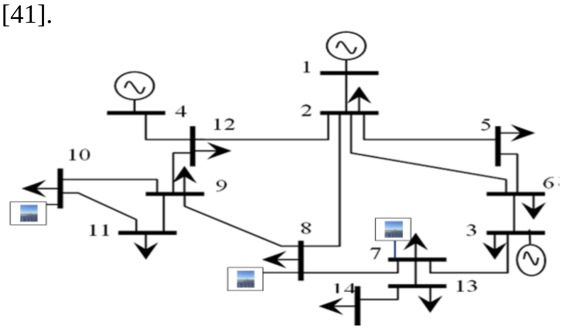

Fig.4. Topologie of the Algerian West Network connected to a renewable energy source

Table 1 group the coefficients of the cost functions providing the fuel quantity in Nm3 / hr including the minimum and maximum powers of each unit [41].

Table 1. data of three unit test system

Unit	P_{ig}^{max}	P_{ig}^{min}	a_i ($/MW²)	b_i ($/MW)	c_i($)
Mersat El Hadjadj	510	30	0.85	150	2000
Tiaret	420	25	0.4	75	850
Ravin Blanc	70	10	1.7	250	3000

The coefficients of the transmission losses

B=1e-3*[0.00546 -0.00052 0.00392
-0.00052 0.01035 -0.00137
0.00392 -0.00137 0.001479]

The powers generated optimal values of production and losses transmitted are grouped in table 2

Table 2. M.H.GA-EVOA compared with C.H.GA-EVOA, GA and EVOA Methods for 3 units system

Method	EVOA	GA	C.H.GA-EVOA	M.H.GA-VOA
Mersat El Hadjadj	295.8071	294.2545	295.7052	295.6249
Tiaret	420	420	420	420
Ravin Blanc	68.4493	70	68.5517	68.6346
P_D(MW)	784.2565	784,2545	784.2569	784.2595
P_L(MW)	2.2574	2.2547	2.2693	2.2594
cost ($/h)	251736.145	251477.237	251718.782	251705.595

The best fuel cost result obtained from the proposed methods EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA is compared in Table 2, which shows that the proposed methods EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA clearly minimized the cost and that the M.H.GA-EVOA has an approximately good solution for the power demand of 782 MW.

Figures 5 and 6 show the convergence characteristics of M.H.GA-EVOA and C.H.GA-EVOA in the search for the optimal generation cost over 70 iterations. We can see that the two techniques, M.H.GA-EVOA and C.H.GA-EVOA, converge fast towards the global optimum, with M.H.GA-EVOA providing the best result.

The first test of optimization (Figure 5) depicts the M.H.GA-EVOA convergence characteristic in the search for the best cost for a three-generator system with PD=782MW. The graphic clearly shows that the solution converges to a high quality solution at an early iteration (10 iterations) and that the fuel cost function value does not change rapidly after 70 iterations.

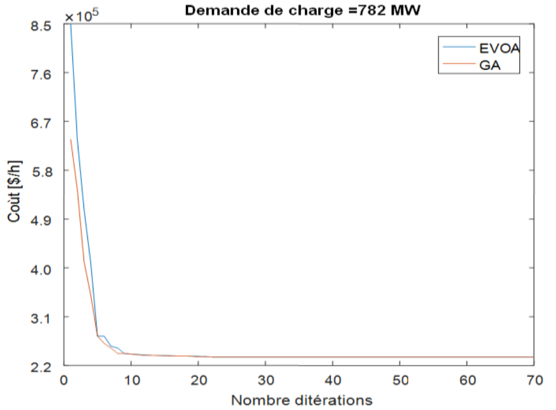

Fig. 5. Convergence characteristic of M.H.GA-EVOA for three generating unit system for P_D=782MW.

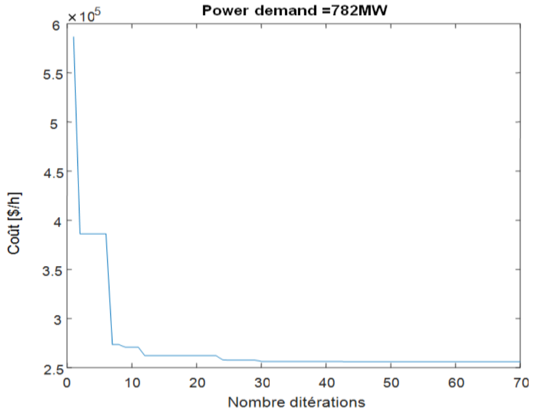

Fig. 6. Convergence characteristic of C.H.GA-EVOA for three generating unit system for P_D=782MW.

The convergence characteristic of C.H.GA-EVOA in the search for the optimal cost for a three-generating-unit system with PD=782MW is shown in Figure 6. The figure clearly shows that the solution is converged to a high quality solution at an early iteration (29 iterations) and that the fuel cost function value does not vary rapidly after 70 iterations.

***B-* electrical network with solar energy production unit**

This application, is interested in the economic dispatching solution with the integration of a solar center.

Table 3. West Algerian installed capacity renewable energies

Renewable Energy unit	Power installed (MW)
SedretLeghzel(Naâma)	20
Ain Skhouna(Saida)	30
Telagh(Sidi-Bel-Abbes)	12
LabiodhSidi Chikh(El-Bayadh)	23

The first test of optimization Figure 7 depicts the M.H.GA-EVOA convergence characteristic when searching for the lowest cost for a three-generator system with PD=782MW. The graphic clearly shows that the solution is converged to a high quality solution at an early iteration (50 iterations)

Table 4. Optimization results of the methods proposed for a western Algerian network connected with renewable energy units.

Method	EVOA	GA	C.H.GA-EVOA	M.H.GA-EVOA
Mersat El Hadjadj	247.1798	277.5990	214.1616	209.2342
Tiaret	419.8988	377.5597	420	420
Ravin Blanc	32.1227	44.3062	65.1486	70
SedretLeghzel(Naâma)	20	20	20	20
Ain Skhouna(Saida)	30	30	30	30
Telagh(Sidi-Bel-Abbes)	12	12	12	12
LabiodhSidi Chikh(El-Bayadh)	23	23	23	23
P_D (MW)	784.2013	784.4649	784.2342	784.3102
P_L (MW)	2.2013	2.4649	2.2342	2.3102
Cost ($/h)	206697.2176	213165.2986	202548.0333	202343.6388

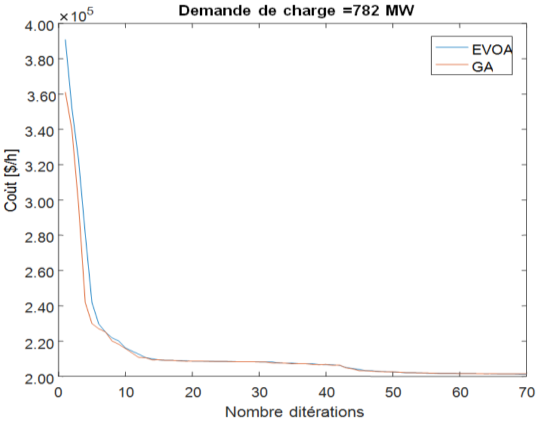

Fig.7. Convergence characteristic of M.H.GA-EVOA for a system of 7 generators for P_D = 782 MW.

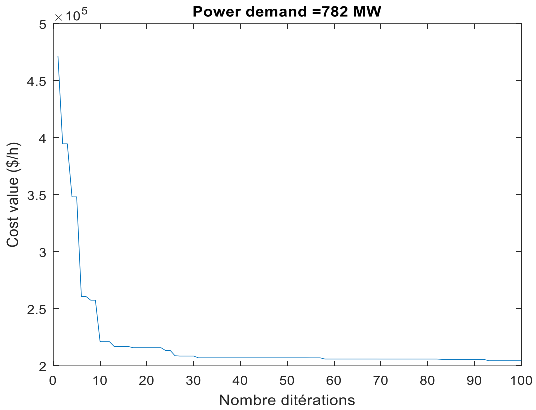

Fig. 8. Convergence characteristic of C.H.GA-EVOA for a system of 7 generators for P_D = 782MW.

and that the fuel cost function value does not vary rapidly after 70 iterations.

Application 2 : A- electrical network without solar energy production unit

The Algerian network characteristics are presented in Table 5 [42]. In this case, the optimization was applied to a dynamic economic dispatch problem with ramping limits constraints of the Algerian 114 bus power plan with 9 classic generators, the total load for 10 time periods of the system is given in table 5, the unit data of this system is given in table 6, and the coefficient are calculated directly with the power flow results.

Table **5**. The total Load for 10 time period

Time from (h)	time to (h)	Power Demand (MW)
1	2	2500
2	3	3000
3	4	3727
4	5	4500
5	6	4800
6	7	5500
7	8	5000
8	9	4100
9	10	3200

Table 7. M.H.GA-EVOA compared with C.H.GA-EVOA, GA and EVOA Methods for Algerian network Pch=3727MW without.

Unit (MW)	M.H.GA-EVOA	C.H.GA-EVOA	EVOA	GA
Pg_4	478.1326	437.2393	438.9471	465.9004
Pg_5	460.3928	505.4518	453.9453	445.3410
Pg_11	99.9996	100	99.9832	99.9967
Pg_15	192.5093	153.8415	156.5098	186.7848
Pg_17	478.5429	414.1632	456.5655	433.0336
Pg_19	188.2747	207.6052	201.6767	196.1141
Pg_52	195.6971	205.8742	205.1403	179.2467
Pg_22	178.6094	211.5898	239.5093	181.2029

Pg_80	192.5800	196.2930	180.0636	197.5288
Pg_83	183.2387	192.0625	222.5353	276.9284
Pg_98	180.8297	204.6862	176.1976	168.2754
Pg_100	599.9835	600	600	599.9702
Pg_101	200	200	200	199.995
Pg_109	99.9554	100	97.6374	99.9715
Pg_111	99.9068	99.8419	99.9339	98.3595
Total output	3828.6531	3828.649	3828.645	3828.649
P_L	101.6531	101.649	101.645	101.649
cost ($/h)	19338.705	19389.89	19404.58	19456.07

Table 6. Generating unit data for 15 units system.

Unit	P_{ig}^{min}	P_{ig}^{max}	a_i($/MW^2)	b_i($/MW)	c_i($)
1	135	1350	0.0085	1.5000	0
2	135	1350	0.0085	1.5000	0
3	10	100	0.0170	2.5000	0
4	30	300	0.0170	2.5000	0
5	135	1350	0.0085	1.5000	0
6	34.5	345	0.0170	2.5000	0
7	34.5	345	0.0170	2.5000	0
8	34.5	345	0.0170	2.500	0
9	34.5	345	0.0170	2.5000	0
10	30	300	0.0170	2.5000	0
11	30	300	0.0170	2.5000	0
12	60	600	0.0030	2.0000	0
13	20	200	0.0030	2.0000	0
14	10	100	0.0170	2.5000	0
15	10	100	0.0170	2.5000	0

Table 7 shows the optimal cost results using M.H.GA-EVOA, C.H.GA-EVOA, GA and EVOA with consideration of losses, the best cost obtained is 19338.7050 ($ / h) found by M.H.GA-EVOA.

From the results indicated in Table 8 it can be clearly seen that M.H.GA-EVOA and C.H.GA-EVOA reduce the total cost and loses compared with GA, EVOA, PSO, FA, BA and HYB.

Table 8. Comparison of the M.H.GA-EVOA, C.H.GA-EVOA, GA and EVOA with different evolutionary methods for Algerian network.

The algorithms used	Total output	Total Cost ($/h)
M.H.GA-EVOA	3828.6531	19338.7050
C.H.GA-EVOA	3828.6492	19389.8918
EVOA	3828.64566	19404.5899
GA	3828.64955	19456.0767
PSO [42]	3833.362	19442,08
FA [43]	3831.5453	19445.51
BA [43]	3830.9054	19439.99
HYB [43]	3830.2206	19441.80

Figure 9 shows the convergence characteristic of M.H.GA-EVOA, while Figure 15 shows the convergence characteristic of C.H.GA-EVOA in the search for the optimal generation cost over 70 iterations. We can see that both methods, M.H.GA-EVOA and C.H.GA-EVOA, converge quickly towards the global optimum, with M.H.GA-EVOA providing the best result.

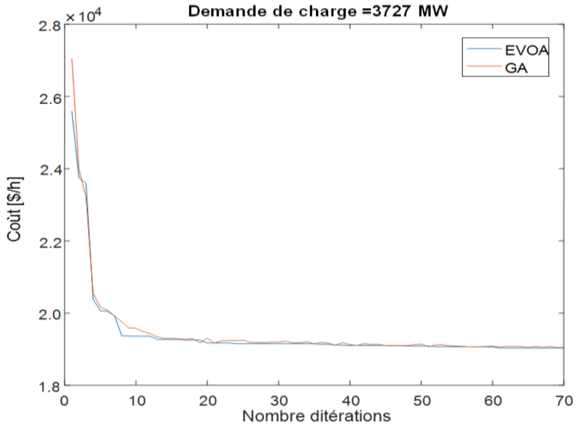

Fig. 9. Convergence characteristic of M.H.GA-EVOA for Algerian network for P_D=3727MW.

Table 9 compares the costs of variable loads in a 15-unit network. The charges are as follows: 2500,

The first test of optimization, Figure 9, shows the convergence characteristic of M.H.GA-EVOA in search of the optimum cost for three generating unit system for P_D=3727MW. It was clearly shown from the figure that the solution is converged to a high quality solution at early iterations (50 iterations) and that there is no rapid change in the fuel cost function value after 70 iterations.

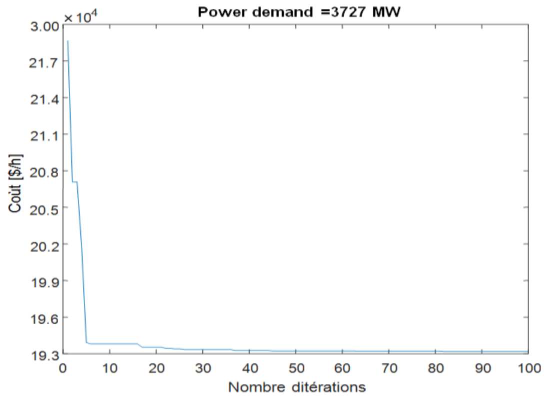

Fig. 10. Convergence characteristic of C.H.GA-EVOA for Algerian network for P_D=3727MW.

Table 9. Economic dispatch results of variable loads for 15 units system.

Total Load	Method							
	M. H.GA-EVOA		C. H.GA-EVOA		EVOA		GA	
	Total output	cost ($/h)	Total output	cost ($/h)	Total output	cost ($/h)	Total output	cost ($/h)
2500	2558.09435	9765.26198	2558.09332	9782.44249	2558.0941	9789.9813	2558.09332	9782.44249
3000	3073.40636	13131.7119	3073.40642	13136.0679	3073.40582	13174.764	3073.40793	13402.2778
3727	3828.6531	19338.7050	3828.6492	19389.8918	3828.64566	19404.5899	3828.64955	19456.0767
4500	4626.3649	27517.1337	4626.3646	27596.8046	4626.3668	27600.8055	4626.3671	27620.5074
4800	4991.7743	31765.604	4991.7747	31776.1741	4991.7756	31808.2059	4991.78244	31825.1459
5500	5786.5298	42615.2437	5786.5224	42723.5746	5786.5187	42770.8054	5786.5218	42782.597
5000	5214.4985	34582.7541	5214.5006	34628.6399	5214.4914	34633.7739	5214.5035	34637.0485
4100	4230.8281	23214.6811	4230.8277	23238.3823	4230.8165	23281.5083	4230.8314	23311.3722
3200	3280.50188	14677.1314	3280.50474	14688.6769	3280.51312	14690.4698	3280.50528	14701.9662

The convergence characteristic of C.H.GA-EVOA in the search for the optimal cost for a 15 generating unit system with P_D=3727MW is shown in Figure 10. The graphic clearly shows that the solution is converged to a high quality solution at an early iteration (45 iterations) and that the fuel cost function value does not vary rapidly after 100 iterations. clearly show that M.H.GA-EVOA reduced the cost regardless of the load.

Table 9 where the charges are successively as 3000, 3727, 4500, 4800, 5500, 5000, 4100, and 3200 MW. The suggested techniques EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA are compared in this study. The results in Table 9 clearly show that M.H.GA-EVOA reduced the cost regardless of the load.

B- electrical network with solar energy production unit

This application, is interested in the economic dispatching solution with the integration of a solar units.

We note that the solar units (Table.10) are located in Algeria so that theese solar units operate and generate around 266.1MW, and connected to the Algerian power system [42, 43].

In this test system, we have applied the methods EVOA, GA, C.H.GA-EVOA and M.H.GA-EVOA in order to improve the function total cost. The application is made on 9 different loads.

Table 10. Renewable energy units installed in Algeria

Renewable Energy unit	Power installed (MW)
Oued Nechou PV (Ghardaia)	1.1
SedretLeghzel (Naâma)	20
Oued El kebrit (Souk Ahras)	15
Ain Skhouna (Saida)	30
Ain El Bel (Djelfa) 1 et 2	53
Lekhneg (Laghouat) 1 et 2	60
Telagh (Sidi-Bel-Abbes)	12
LabiodhSidi Chikh (El-Bayadh)	23
El Hdjira (Ouargla)	30
Ain-El-Melh (M'Sila)	20
OuedEl Ma (Batna)	02

The obtained findings show that the suggested approaches have a certain interest in terms of dependable convergence toward a global optimum and decreased overall cost reduction. When compared to EVOA, GA, C.H.GA-EVOA, and other approaches, the M.H.GA-EVOA method converges faster.

Table 11 compares the best fuel cost results derived from the suggested techniques EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA, as well as other optimization algorithms, showing that the proposed methods EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA clearly minimized the cost. When compared to other optimization methods, the M. H GA-EVOA provides a rather excellent answer for the 3727 MW power requirement.

Figure 11 depicts the M.H.GA-EVOA convergence characteristic in the search for the best cost for a 26-generator system with PD=3727MW. The figure clearly shows that the solution is converged to a high quality solution at early iterations (18 iterations) and that the fuel cost function value does not vary rapidly after 70 iterations.

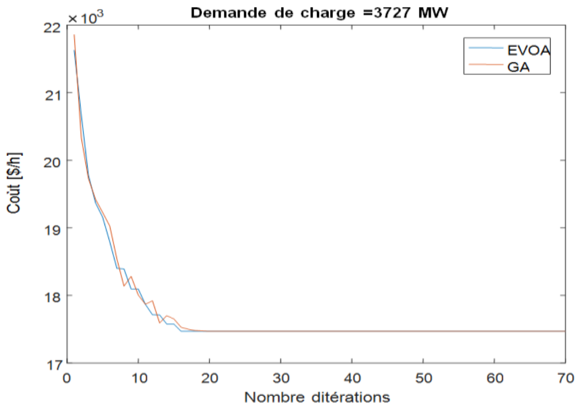

Fig.11**.** Convergence characteristic of M.H.GA-EVOA for Algerian network for P_D=3727MW.

Figure 11 shows the convergence characteristic of M.H.GA-EVOA in search of the optimum cost for 26 generating unit system for P_D=3727MW. It was clearly shown from the figure that the solution is converged to a high quality solution at early

Table 11. Comparison of proposed methods for Algerian network connected to solar units

Unit (MW)	**M.H.GA-EVOA**	**C.H.GA-EVOA**	**EVOA**	**GA**
Pg_4	407.8376	595.6580	593.5651	509.9105
Pg_5	564.6554	255.1066	365.6622	291.1171
Pg_11	67.8266	88.8250	44.6844	73.8813
Pg_15	137.6606	197.2694	225.7023	95.9382
Pg_17	379.4056	440.1205	528.2573	404.1019
Pg_19	162.3120	167.9163	89.0690	291.1748
Pg_52	140.0823	260.1457	178.6339	154.3353
Pg_22	129.2858	188.0164	131.1582	185.3904
Pg_80	247.5282	126.7413	78.2766	222.8013
Pg_83	209.5447	151.6242	261.1066	238.4779
Pg_98	144.5444	172.6281	114.9896	256.0692
Pg_100	600	577,8229	600	600
Pg_101	199.7370	169.6443	198.1409	200
Pg_109	73.2989	84.4052	75.0135	10
Pg_111	98.6178	86.4112	78.0783	29.2773
PV (Ghardaia)	1.1	1.1	1.1	1.1
PV (Naâma)	20	20	20	20
PV (Souk Ahras)	15	15	15	15
PV (Saida)	30	30	30	30
PV (Djelfa) 1 et 2	53	53	53	53
PV (Laghouat) 1 et 2	60	60	60	60
PV (Sidi-Bel-Abbes)	12	12	12	12
PV (El-Bayadh)	23	23	23	23
PV (Ouargla)	30	30	30	30
PV (M'Sila)	20	20	20	20
PV (Batna)	02	02	02	02
Total output	3828.4376	3828.4358	3828.4387	3828.5757
P_L	101.4376	101.4358	3828.4387	3828.5757
cost ($/h)	17567.1261	17989.8154	18277.2698	18630.8913

Table 12. Economic dispatch results of variable loads for 15 units system connected 11 solar units.

Total Load	Method							
	M.H.GA-EVOA		C. H.GA-EVOA		EVOA		GA	
	Total output	cost ($/h)	Total output	cost ($/h)	Total output	cost ($/h)	Total output	cost ($/h)
2500	2557.4992	8807.8791	2557.4948	9002.6914	2557.5099	9104.9572	2557.4954	9231.3657
3000	3070.1346	11643.7079	3070.1069	11965.4191	3070.1021	12158.3196	3070.1084	12414.2895
3727	3828.4376	17567.1260	3828.4358	17989.8154	3828.4387	18277.2698	3828.5757	18630.8912
4500	4655.1971	25248.0293	4655.1944	26181.7111	4655.2050	26428.3932	4655.2053	26828.5993
4800	4982.6792	29051.5304	4982.7098	30345.5475	4982.7652	30430.5097	4982.7136	31171.9672
5500	5773.8139	39938.50545	5773.8327	40065.7755	5773.812293	41253.8539	5773.8326	42537.7766
5000	5204.8244	32819.9047	5204.7926	33155.7217	5204.8230	33382.6388	5204.8144	33589.2335
4100	4225.1666	21710.7576	4225.1935	22028.6917	4225.1683	22192.3119	4225.1928	22416.4079
3200	2557.5033	8648.5321	2557.4978	8745.0599	2557.4977	8791.2864	2557.5158	8889.6479

iterations (18 iterations) and that there is no rapid change in the fuel cost function value after 70 iterations.

In order to improve the function total cost, we used the techniques EVOA, GA, C.H.GA-EVOA, and M.H.GA-EVOA in this test system. The software is tested on nine different loads.

The obtained findings show that the suggested approaches have a certain interest in terms of dependable convergence toward a global optimum and decreased overall cost reduction. When compared to EVOA, GA, C.H.GA-EVOA, and other approaches, the M.H.GA-EVOA method converges faster.

Figure 12 shows the convergence characteristic of C.H.GA-EVOA in search of the optimum cost for 26 generators unit system for P_D=3727MW. It was clearly shown from the figure that the solution is converged to a high quality solution at early iterations (28 iterations) and that there is no rapid change in the fuel cost function value after 70 iterations.

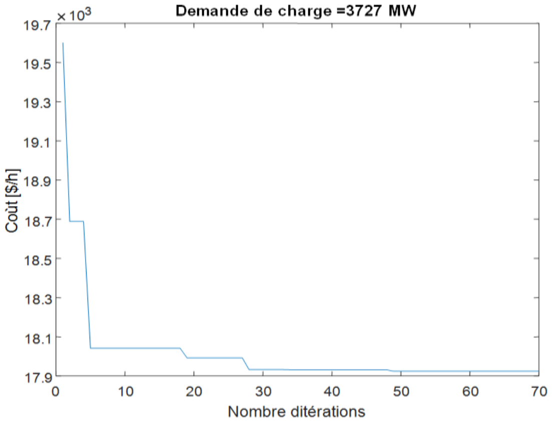

Fig.12. Convergence characteristic of C.H.GA-EVOA for Algerian network for P_D=3727MW.

A comparison of the cost in the case of variable loads in a network of 26 units system is shown in

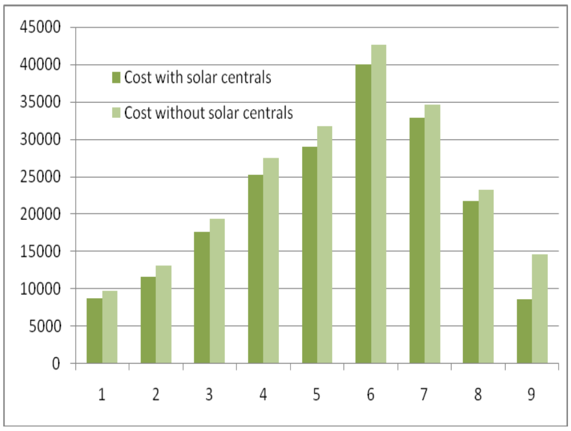

Fig.13. Comparaison of the cost obtained by M.H.GA-EVOA in power system without and with connection to solar units.

Note: Figure 13. Shows that the cost is better minimized when the power system is connected to solar units.

5. Conclusion

This study makes a contribution to the solution of the problem of economic dispatching; four techniques were investigated to address the problem.

In order to address the minimization of the objective function, the employment of these approaches in the optimum distribution of active powers necessitates a thorough evaluation of the various parameters.

The four algorithms, namely (GA), (EVOA), and the hybrid algorithm (C.H.GA-EVOA), as well as the hybrid algorithm in its developed version (M.H.GA-EVOA), were applied on two Algerian electricity networks, the first of which contains 7 system units and the second of which contains 26 system units. The Algerian electricity network was optimized without or with connections.

The results of the metaheuristic approaches used (GA), (EVOA) are of particular relevance in terms of dependable convergence toward loss minimization and total cost minimization. The capacity of metaheuristic strategies to reach the optimal value of the cost of production is demonstrated by a comparison of results acquired from metaheuristic techniques. The most successful approach is always the EVOA method.

The results show that when the electrical network is connected to renewable energy production units, the cost function is better reduced

REFERENCES

1. Irina C, Elias K. Recent methodologies and approaches for the economic dispatch of generation in power systems. Int trans Electr Energ Syst. 2013;23:1002-27. https:// doi: 10.1002/etep.1635
2. Belkacem M, Kamel S. Interactive gravitational search algorithm and pattern search algorithm s for practical dynamic economic dispatch. Int T Electr Energy. 2015; 25:2289-09.
3. Si Tayeb, A. Bouzeboudja, H. Laroussé B, Naama B, Rezzak D. Egyptian Vulture Optimization For Combined Economic and Emission Dispatch New Meta- heuristic Algorithm. Journal of Electrical Engineering. 2017 17: 4-54.
4. Haiwang Z, Qing X, Yang W, Chongqing K. Dynamic economic dispatch considering transmission losses using quadratically constrained quadratic Program method. Power Syst IEEE Trans. 2013; 28(3):2232-41. https:// doi: 10.1109/TPWRS.2013.2254503
5. BOUALLAG K, DJEKIDEL R, BESSEDIK S. Optimisation de la tension induite sur une canalisation enterrée à partir de lignes électriques HT à l'aide de l'algorithme Grasshopper (GOA). DIAGNOSTYKA.2021;22(2):105-115. https://doi.org/10.29354/diag/138719
6. Ding T, Bo R, Li F, Sun H. A Bi-Level branch and bound method for economic dispatch with disjoint prohibited zones considering network losses. IEEE Trans Power Syst. 2015;30 (6):2841-55. https://doi : 10.1109/TPWRS.2014.2375322
7. Ehsan A, Mahmood J. An improved cuckoo search algorithm for power economic load dispatch" Int T Electr Energy. 2015; 25:958-75. https://doi : 10.1002/etep.1878
8. Stambouli AB. Algerian renewable energy assessment: the challenge of sustainability. Energy Policy.2011;39(8),4507-4519. https://doi.org/10.1016/j.enpol.2010.10.005
9. Palanichamy C, Babu NS. Analytical solution for combined economic and emissions dispatch. Electr Power Syst Res. 2008;78(7):1129-37. https://doi:10.1016/j.epsr.2007.09.005
10. Adarsh BR, Raghunathan T, Jayabarathi T, Yang X-S. Economic dispatch using chaotic bat algorithm. Energy. 2016; 666-75. http://dx.doi.org/10.1016/j.energy.2015.12.096
11. Gwo-Ching L. A novel evolutionary algorithm for dynamic economic dispatch with energy saving and emission reduction in power system integrated wind power. Energy. 2011; 36, 2, 1018-1029. https://doi.org/10.1016/j.energy.2010.12.006
12. Basu M, Chowdhury A. Cuckoo search algorithm for

economic dispatch. Energy. 2013;113:99-108. http://dx.doi.org/10.1016/j.energy.2013.07.011
13. Si Tayeb, A. Bouzeboudja, H. Application of a New Meta-heuristic Algorithm using Egyptian Vulture Optimization for Economic. *PRZEGLĄD ELEKTROTECHNICZNY*, R. 95 NR 6.2019. http://doi:10.15199/48.2019.06.11
14. He X, Rao Y, Huang J. A novel algorithm for economic load dispatch of power systems. Neurocomputing. 2016; 171(1):1454-61. https://doi.org/10.1016/j.neucom.2015.07.107
15. Basu M. Kinetic gas molecule optimization for nonconvex economic dispatch problem. Int J Elec Power 2016; 80:325-32. http://dx.doi.org/10.1016/j.ijepes.2016.02.005
16. Slimani L, Bouktir T .Optimal Power Flow Solution of the Algerian Electrical Network using Differential Evolution Algorithm. TELKOMNIKA. 2012; 10,2: 199-210. https:// doi: 10.11591/telkomnika.v10i2.672
17. Arag_on VS, Esquivel SC, Coello Coello CA. An immune algorithm with power redistribution for solving economic dispatch problems. Inform Sciences .2015;295:609-32. http://dx.doi.org/10.1016/j.ins.2014.10.026
18. B Larouci, L Benasla, A Belmadani. Cuckoo Search Algorithm for Solving Economic Power Dispatch Problem with Consideration of Facts Devices. UPB Sci. Bull, Series C. 2017; 79-81. https:// doi: 10.13140/RG.2.2.17880.21766
19. Shaw B, Mukherjee V, Ghoshal SP. Solution of economic dispatch problems by seeker optimization algorithm. Expert Syst Appl. 2012; 39(1):508-519. https://doi.org/10.1016/j.eswa.2011.07.041
20. Zare K, Haque MT, Davoodi E. Solving non-convex economic dispatch problem with valve point effects using modified group search optimizer method. Electr Pow Syst Res. 2012; 84(1):83-9. https://doi.org/10.1016/j.epsr.2011.10.004
21. Secui DC. A modified symbiotic organisms search algorithm for large scale economic dispatch problem with valve-point effects. Energy. 2016; 113:366-84. https://doi.org/10.1016/j.energy.2016.07.056
22. Pradhan M, Roy PK, Pal T. Grey wolf optimization applied to economic load dispatch problems. Int J Electr Power. 2016; 83:325-334. https://doi.org/10.1016/j.ijepes.2016.04.034
23. Jayabarathi T, Raghunathan T, Adarsh BR, Suganthan PN. Economic dispatch using hybrid grey wolf optimizer. Energy. 2016; 111:630-41. https://doi.org/10.1016/j.energy.2016.05.105
24. Meng A, Li J, Yin H. An efficient crisscross optimization solution to large-scale non-convex economic load dispatch with multiple fuel types and valve-point effects. Energy. 2016; 113:1147-61. https://doi.org/10.1016/j.energy.2016.07.138
25. Dexuan Z , Steven L, Zongyan L, Xiangyong K. A new global particle swarm optimization for the economic emission dispatch with or without transmission losses. Energy Conversion and Management.2017;13945-70. http://dx.doi.org/10.1016/j.enconman.2017.02.035.
26. Secui DC. A new modified artificial bee colony algorithm for the economic dispatch problem. Energy Convers Manage. 2015; 89:43-62. https://doi.org/10.1016/j.enconman.2014.09.034
27. Fraga ES, Yang L, Papageorgiou LG. On the modelling of valve point loadings for power electricity dispatch. Appl Energy. 2012; 91:301-3. https://doi.org/10.1016/j.apenergy.2011.10.001
28. Pothiya S, Ngamroo I, Kongprawechnon W. Ant colony optimisation for economic dispatch problem with non-smooth cost functions. Int J Electr Power Energy Syst. 2010; 32(5):478-87. https://doi.org/10.1016/j.ijepes.2009.09.016
29. Niknam T. Doagou M, H Zeinoddini, Meymand H. A new particle swarm optimization for non-convex economic dispatch. Int T Electr Energy. 2010; 21(1):656-79. https://doi: 10.1002/etep.468
30. Barisal AK, Prusty RC. Large scale economic dispatch of power systems using oppositional invasive weed optimization. Appl Soft Comput. 2015; 29:122-37. https://doi.org/10.1016/j.asoc.2014.12.014
31. Meng K, Wang HG, Dong Z, Wong KP. Quantum-inspired particle swarm optimization for valve-point economic load dispatch. IEEE T Power Syst. 2010; 25(1):215-22. https://doi: 10.1109/TPWRS.2009.2036481
32. Subbraj P,Rengaraij R, Salivahanan S, Senthikumar TR. Particle swarm optimization with modified stochastic acceleration facrors solving large scale economic dispatch problem. Int J Elec Power. 2010; 32:1014-23. https://doi.org/10.1016/j.ijepes.2010.02.003
33. Al-Betar MA, Awadallah MA, Khader AT, Bolaji ALA. Tournament-based harmony search algorithm for non-convex economic load dispatch problem. Appl Soft Comput. 2016; 47:449-59. https://doi.org/10.1016/j.asoc.2016.05.034
34. Dilip K, Nandhini M. Adapting Egyptian Vulture Optimization Algorithm for Vehicle Routing Problem. International Journal of Computer Science and Information Technologies. 2016; 7(3):1199-204.
35. Chiranjib S, Sanjeev S, Anupam S .Egyptian Vulture Optimization Algorithm – A New Nature Inspired Meta-heuristics for Knapsack Problem. IC2IT.2013 ;209:227-37. https://doi.org/10.1007/978-3-642-37371-8_26
36. Gaing, Z.-L. Particle swarm optimization to solving the economic dispatch considering the generator constraints. IEEE T Power Sys. 2003 ; (3):1187-95. https://doi: 10.1109/TPWRS.2003.814889
37. Victoire T, Jeyakumar A E. Discussion of particle swarm optimization to solving the economic dispatch considering the generator constraints. IEEE T Power Sys.2004;19(4):2121-23. https://doi: 10.1109/TPWRS.2004.831709
38. Victoire T, Jeyakumar A E. Hybrid PSO-SQP for economic dispatch with valve-point effect. Electr Pow Syst Res. 2004; 71(1):51-59. https://doi:10.1016/j.epsr.2003.12.017
39. Sinha N, Chakrabarti R, Chattopadhyay P K. Evolutionary programming techniques for economic load dispatch. IEEE T Evolut Comput. 2003;7(1):83-94. https://doi: 10.1109/TEVC.2002.806788
40. Duman S, güvenç U, yörükeren N. gravitational search algorithm for economic dispatch with valve-point effects. int rev electr eng. 2010; 5(6):2890-5.
41. Al-Sumait J S, Al-Othman A K, Sykulski J K. Application of pattern search method to power system valve-point economic load dispatch. Int J Elec Power. 2007; 29(10):720-30. https://doi:10.1016/j.ijepes.2007.06.016
42. Belmadani, A, Benasla L, Rahli M. The dynamic economic dispatch including wind power injection in the western algerian electrical power system. Acta Polytechnica Hungarica. 2011; 8(5), 191-204.

43. Souag S, Benhamida F. A Dynamic Power System Economic Dispatch Enhancement by Wind Integration Considering Ramping Constraint - Application to Algerian Power System. international journal of renewable energy research. 2015; 5, 3.
44. Yamina A G, Hamid B. Resolution of Economic Dispatch Problem of the Algerian Network using Hybrid Metaheuristic. Electrotehnică, Electronică, Automatică (EEA). 2017; 65(1),91-96.

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Abdelkader Si TAYEB was born on 05.12.1981.
In 2007, she graduated the Department of Electrotechnic of the Faculty of Electrical Enginnering at University Mascara She defended her master in 2011; she prepared the PhD degree in Electrical Engineering department of at University (USTO) in Algeria.
Her research activities focusing a practical method based on meta-heuristic for larg scale power system.
Correspondence address: si_tayeb12@yahoo.fr

Benyekhlef LAROUCI is a PhD in Electrical Engineering, was born in 1985 in Mascara, Algeria. He is currently works at Kasdi Merbah University Ouargla, Algeria. He received a Ph.D degree and Magister in Electricals engineering from the University of Science and technology of Oran, Algeria in 2018. He received a Diploma Engineer in Electrotechnics from the University of Mascara in 2007. His research activities are in the power system optimization problems including economic dispatch, the heuristic optimization techniques and also include the control of large power systems, Facts devices and the unified power flow controller.

Daoud REZZAK was born in Jijel, Algeria, in 1984. He received the B.Sc. degrees in electrical engineering, from the University of Jijel, Algeria in 2008,theM.Sc. degrees in Electrical Engineering from thePolytechnic Military Academy, Algiers, Algeria in 2011 andthe PhD degreesin Electrical Engineering, from the University of Jijel, Algeria in 2017.
In 2014, he joined theRenewable Energy Applied Research Unit, Ghardaïa, Algeria, as a Research associate. Since April2021, he is a master research class A.His research interests include power converters design, control technics and energy management in hybrid power systems.

Yehya HOUAM received his Engineer degree in Automatic control from Tebessa University Algeria, in 2006, his Magister of Science (M.Sc) grade and Doctor of Science (Ph.D) grade in Electrical Engineering (Automatic Control) from Biskra University, Algeria, respectively in 2013, and 2021. He is currently a Researcher since 2014 in hybrid energy systems team. Mini Solar power plant division in Unité de Recherche Appliquée en Energies Renouvelables (URAER), Ghardaïa, Algeria, it is affiliate of Centre de Développement des Energies Renouvelables (CDER), Algiers, Algeria. His research interests include the applications of soft computing (metaheuristic) optimization techniques and power electronics to renewable energy systems (RES), Energy management for autonomous renewable energy systems.

Hami BOUZEBOUDJA was born on 04.03.1965.
In1993 he graduated at the electrotechnical Department of the Faculty of Electrical Engineering at University (USTO) in Algeria.
He graduated the master in the field optimal power flow problems in 1996.
Presently, he is a Professor in the Electrical Engineering department of USTO, his scientific research is focusing on practical methods based on genetic algorithms for solving the economic dispatch problem of complex systems
Correspondence address : hbouzeboudja@yahoo.fr

Bouchakour ABDELHAK was born in Algeria in 1984. He obtained his master's degree in electrical engineering, option renewable energies and sustainable development from the University Abdelhalim Ibn Badis in Algeria. Then he obtained his doctoral degree in 2018, in electrical engineering, Option: electrical control from the Univ Djillali liabes of Sidi Belabes.He hold a post of research supervisor A in an applied research center in renewable energy.