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The Use of Grey Wolf Optimizer (GWO) for Solving the Economic Dispatch Problems based on Renewable Energy in Algeria A case study of "Naama Site"

Abstract. *The use of renewable energy sources worldwide will increase, leading to a more sustainable energy mix, reduced greenhouse gas emissions and reduced dependence on oil. Therefore, the integration of renewable energy systems into the grid is very important. Wind and solar energy are one of the renewable means of electricity production that is part of the global debate on the future of energy production and use and their effects on the environment. The main purpose of this study was to present a technique on how to optimize integrating a wind and solar energy in Algeria. A case study (Naama site). In this study, a scenario will be taken for analyzing the impact of the integration of this renewable energy (wind/solar), on the economic dispatch problems where it has been resolved with a new naturally inspired algorithm called a Gray Wolf Optimizer algorithm (GWO), the results obtained show that the grey wolf optimizer used in this paper either matches or outperforms the other methods in terms of solution of economic dispatch problems.*

Streszczenie. *W artykule optymlizację zintegrowania żródeł energii wiatroej i słonecznej z uwzględnieniem aspektów ekonomicznych na przykładzie Algerii. Do optymalizacji wykorzystano algorytm nazwany Gray Wolf Optimizer algorithm (GWO).* ***Wykorzystanie algorytmu Gray Wolf Optimizer do optymalizacji integracji z siecią źródeł energii odnawialnej z uwzględnieniem aspektów ekonomicznych.***

Keywords: Economic dispatch – gray wolf optimizer (GWO) – hybrid power system – solar energy – wind energy.
Słowa kluczowe: odnawialne źródła energii,algorytm gray wolf optimizer (GWO)

Introduction

Energy has served as an important source of economy for many decades. What is meant by energy? Energy is for instance, natural gas, diesel, coal, and electricity, this energy is needed to run vehicles, devices, machines: to fertilize and irrigate lands, harvest crops, to light up and heat apartments, buildings and factories. Since the use of energy is involved in each step of previous fields, surely people's welfare is likely to go down in the lack of energy. [1].

Fossil fuels like coal, oil and natural gas are currently the world's primary energy sources. The heavy dependence on the fossil fuel reduced the natural reserve of it. To take care of the balance and limited life of conventional sources which creates danger on the environment, research on alternative sources of energy is carried out [2].

In current decades, renewable energy resources have received considerable attention in both grid independent and on-grid applications. The benefits associated with renewable resources include: reducing environmental pollution, endlessness, improved power quality, and reliability, and saving power for the next generations [3, 4].

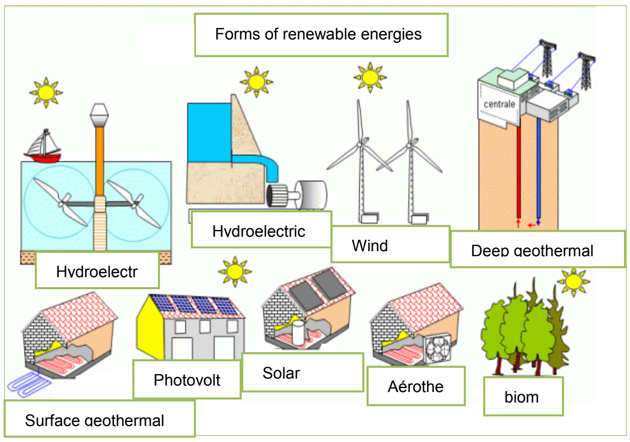
Engineers and scientists are increasingly trying to find and use alternative energy sources. The three most widely used renewable energy sources are hydro, wind and photovoltaic (PV) [5].

Fig.1. Most common forms of renewable energy

A well-engineered renewable energy system can reduce costing of energy, consequently improving lifestyle [6]. Hybrid power system uses more than one type of generator, usually, a conventional generator powered by diesel, and a renewable energy source such as wind energy and photovoltaic (PV). Various "hybrid" system of renewable energy sources and diesel generators are currently being developed and marketed [7].

The present paper comprehensively reviews the hybridization of wind, PV energy and gas turbine, installed in Naama-Algeria. This study will analyze the impact of the integration of renewable energy on the economic dispatch problem that will be solved with a gray wolf optimizer algorithm (GWO). Simulation results show that the emission is minimized with the inclusion of these renewable energy sources. In addition to the effectiveness of the proposed algorithm.

Fig.2. Forms of renewable energy (RE)



What is Renewable Energy?

Renewable Energy (RE) has been defined as energy flows that occur naturally and repeatedly in the environment and can be harnessed for human benefit. The widely used description might be energy produced from a renewable and/or sustainable fuel source. It might be named: «renewable», «sustainable», or «alternative» for energy (that is, an alternative to traditional fossil fuels). Renewable energy is generated from natural resources such as wind, sunlight, tide, hydro, biomass and geothermal [8, 9].

The main focus of this study is on two types of energies; solar power and wind energy.

A. Solar Energy

Sun produces heat and light that is necessary for life. Solar radiation is used to heat and produce electricity. A photovoltaic generation has been existing for a long time and its technology has improved immensely. The first use was in space, now it is being applied to terrestrial applications such as powering remote or isolated areas and feeding utility grids [10].

The power generated from the PV modules depends on the temperature and the solar radiation [11, 12]. To choose the appropriate solar module for a particular location, it is necessary to study the temperature over the whole year to ensure the efficiency of the PV module [13, 14, and 15].

The maximum power obtained from PV modules based on solar radiation and temperature is presented as follows:

$$P_\rho = \eta_v A_p G_r \left(1 - T_C \delta_T\right) \quad (1)$$

where η_V is the power generation efficiency of the PV. A_p refers to the complete area of the PV modules. G_r is the solar irradiated while T_C represents the temperature coefficient. δ_T is the temperature error based on the reference cell temperature [16, 17].

However, based on the solar irradiation radiation and temperature, the average obtainable power from the PV array is given by:

$$P_\rho = \int_0^{G_m} P_\rho f d_{G1} \quad (2)$$

where G_m the maximum solar radiance and f is a beta distribution that correctly describes the solar radiance as a random variable [18, 19, and 20].

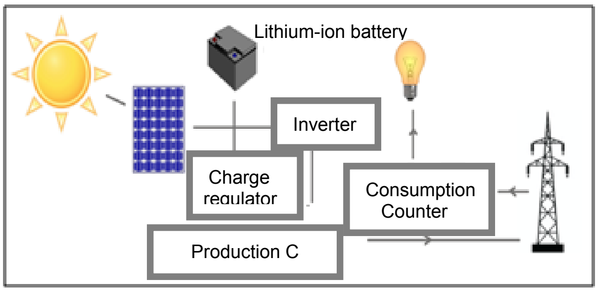


Fig.3. Solar energy conversion chain

B. Wind Power

The wind is a powerful source of energy, and one of the first to have been used by humanity. It makes sailing boats, fly kites. Now, it is used to produce electricity. It is among the list of green energy resources, wind electric power has had the fastest growth in the world (30% annually) in different countries over the last 20 years [21, 22].

How is wind energy employed?

Wind energy is produced by using an aero-generator device such as a wind turbine or a windmill. Wind energy can be used in two ways:

1. Conversion of mechanical energy: the wind is drive sailing vessel or sand yacht, to pump water (Mallorca mills, pumping wind turbines to irrigate or water livestock) or to spin the grinding wheel of a mill.
2. Transformation into electrical energy: the wind turbine is coupled with a generator to manufacture alternating current (Wind power is converted into electricity by magnets moving past stationary coils of wire known as the stator. As the magnets pass the stator AC electricity is produced), for connected to an electrical network or it is then converted into DC electricity which can be used to charge batteries [23, 24].

Other uses for wind energy:

The pumping of water by means of multi-blade wind turbines which still widespread in countries or agricultural areas that do not have electricity. Recharging batteries to provide basic electricity (lighting, radio or TV) to an isolated family, using small wind turbines, (widely used in China and Mongolia and Algerian Nomads).

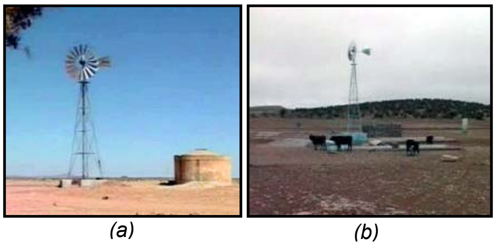


Fig.4. Wind energy in Algeria : (a) For drinking water supply at Mecheria (b) For pumping water to livestock at Naama

The mechanical power recovered by a wind turbine can be written in the form [23, 25, and 26]:

$$P_W = \frac{1}{2} C_P \rho \tau R_W^2 V_W^3 \quad (3)$$

Where C_P, is the aerodynamic coefficient of turbine power (it characterizes the aptitude of the aero-generator to collect wind power), ρ is the air density, R_p the turbine ray and V_W wind speed. The power coefficient value C_P depends on the rotation speed of the turbine and wind speed.

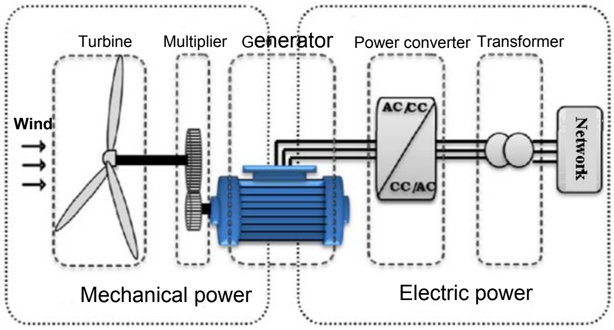


Fig.5. Principle of conversion of the kinetic energy of wind into electrical energy

Solar and Wind Potential in Algeria

The requirements of sustainable development lead to an increase in the production of electricity from renewable sources. Wind and solar are currently the most competitive resources and the improvement of wind turbines and solar panels lead to a great deal of research especially in the field of electrical engineering.

The exploitation of renewable resources is booming in many countries, for example: Algeria is a vast country with a very diversified climate. It has two large distinct geographical zones, the northern Mediterranean and the Southern Sahara. it can become a good competitor in this domain.

Algeria receives an average of 3000 hours/year of solar radiation; it has the most important solar potential of the Mediterranean (169440TWh/year). The average of the received solar energy in coastal regions is 1700 kWh/m²/year while it is 1900 kWh/m²/year on highlands and 2650 kWh/m²/year in the Sahara [27] (see Table I).

It has been proved that, the solar potential of the Sahara can cover all the needs of energy in the world if we put the necessary amount of investments in this field [28].

Table 1.The Sunrise rate for each region of Algeria, [27]

Regions area	Coastal areas	High plateaus	Sahara
	4%	10%	86%
Average duration of sunshine (hours/year)	2650	3000	3500
Received average energy (Kwh/m^2/year)	1700	1900	2650

A. Presentation and Location of the Naama Site

Naama site is located in the southwest of Algeria. It contains 19 small districts and municipalities. Ain-Sefra and Mecheria are the biggest municipalities of the province. It is situated between North Atlas and the Saharan Atlas to the South; It covers an area of about 29825 km^2 and a population of about 225530 either a density average of 7.6 inhabitants per km2 (see Fig. 6). [29]

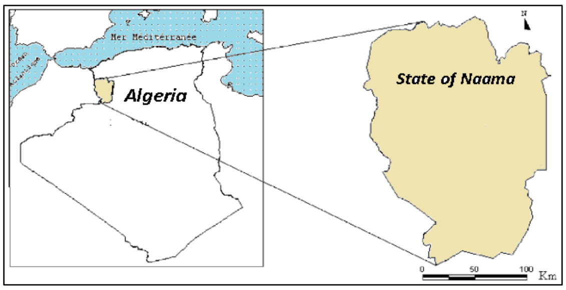


Fig.6. Location of Naama site

B. Statistical Study of the Solar Potential in Naama

The solar field is a set of data describing the evolution of the available solar radiation at a given site and within a given period.

Table 2. Average Temperatures in Naama (Ain Sefra/Mecheria) From the Year 2018 [30]

Stations	Naama			
	Ain-Sefra		Mecheria	
Temperatures	Max (°C)	Min (°C)	Max (°C)	Min (°C)
January	11.6	4.3	9.3	2.5
February	20.2	1.5	14.5	2.8
March	26.6	16.9	26.8	9.1
April	16.9	7.2	16.7	5.8
May	26.5	15	25.5	12.4
June	33.1	18.6	31.1	15.2
July	39	24.4	40.7	23.8
August	34.7	21.3	35.4	19.6
September	31.2	17.4	30.6	15.5
October	26.3	17	22.1	15.8
November	/	/	/	/
December	/	/	/	/

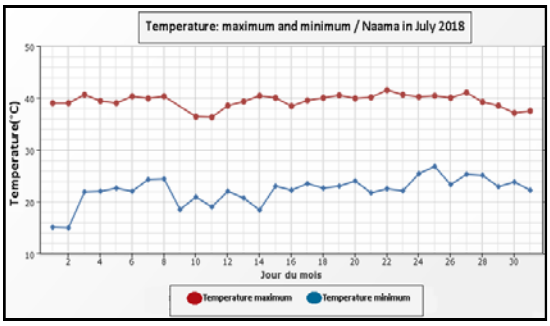


Fig.7. Temperature: maximum and minimum of the Naama region in July 2018

C. Statistical Study of the Wind Potential in Naama

The estimation of wind energy available in a given region remains one of the most important steps before a possible implantation of a wind park. Thus, the geographical distribution of a deposit remains very complex due to its reliance on several parameters such as the climate, the topography of the terrain and soil roughness. [31], [32]

Table 3.A monthly average speed and average power density for Naama (Ain sefra/Mecheria) [31]

	Naama			
Stations	Ain-Sefra		Mecheria	
Parameters	V(m/s)	P(W/m²)	V(m/s)	P(W/m²)
January	2,26	37,56	4,70	154,30
February	2,63	39,43	5,12	185,07
March	2,97	43,15	5,32	164,64
April	3,28	50,93	5,64	188,62
May	3,24	43,94	5,57	164,72
June	2,80	29,03	5,03	114,48
July	2,40	17,74	4,73	91,84
August	2,54	19,31	4,61	90,19
September	2,39	21,79	4,72	104,99
October	2,10	19,13	4,44	100,37
November	2,05	24,39	4,61	126,68
December	2,17	27,23	5,03	156,00

Due to the abundance of solar potential and the very high wind speed in the Naama region, we have considered integrating the two renewable energies (Solar and Wind) in order to achieve electricity self-sufficiency. To do this, a technical and economic study must be carried out using optimization methods. When we combine the three energy sources (Wind/Solar/Micro Turbine a Gas), we will study it using a new naturally inspired algorithm called Grey Wolf Optimizer (GWO)), the results will be presented in tabular form and in figures.

Mathematical formulation of the problem

The economic dispatch problem, which is used to minimize the cost of production of real power, can generally be stated as follows:

(4) $$\min\left[\sum_{i=1}^{n_g} F_i(P_i)\right]$$

(5) $$\sum_{i=1}^{n_g} P_i = P_D + P_L$$

(6) $$P_i^{\min} \le P_i \le P_i^{\max}$$

where most often $F_i(P_i)$ is a quadratic polynomial:

(7) $$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i$$

where F is the total fuel cost of the system, n_g is the number of generators, and a_i, b_i and c_i are the cost coefficients of the i^{th} generating unit, P_i real power generation, P_D is the total demand, P_L represents the active transmission losses, P_i^{min}, and P_i^{max} are the minimum and maximum limits for the production of the i^{th} unit.

Expression of the transmission losses as a function of generated power is given by:

(8) $$P_L = \sum_{j=1}^{ng}\sum_{i=1}^{ng} P_j B_{ji} P_i + \sum_{j=1}^{ng} B_{0j} P_j + B_{00}$$

Intelligent Optimization Algorithm Grey Wolf Optimizer

Grey wolf optimization is one of the biologically inspired optimization algorithm proposed in 2014 by Mirjalili et al. The GWO algorithm mimics the hunting nature of grey wolf family. Grey wolves usually prefer to be in a pack. The pack size of grey wolves is varying from 5 to 12 in number. They have a strict social dominant 4 level hierarchy. Grey wolves are hierarchically categorized into alpha (α), beta (β), delta (δ), and omega (ω) in the pack, the pack works for hunting, searching for prey, encircling prey and attacking prey. The leaders are a male and female, called alphas. The leader alpha decides the pack's action. The entire pack acknowledges the alpha by holding their tails down. Only the alphas mate in the pack. The alpha dominates as a good administrator. It may not be the strongest member of the pack [33, 34, 35].

The second level consists of beta. They are subordinate wolves that help the alpha in decision-making or other pack activities. The beta wolf can be either male or female and is the next best successor in case one of the alpha wolves ceases. It plays the role of an advisor to the alpha and dis-cipliner for the pack. Omegas are in the third level from the top. They have to submit to all the other dominant wolves. They are the last wolves that are allowed to eat [4]-[36].

Though Omega is least ranked, the whole pack faces internal fighting and problems without them. They help to satisfy the whole pack and maintaining the dominance structure. If a wolf is not an alpha, beta, or omega, he/she is called subordinate (or delta in some references). Delta wolves have to submit to alphas and betas, but they dominate the omega [37], [38].

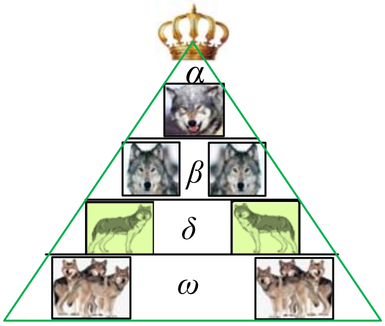


Fig.8. Social hierarchy of a pack of grey wolves.

Social behaviour of grey wolves is:

- Tracking, chasing, and approaching the prey,
- Pursuing, encircling, and harassing the prey, until it stops moving,
- Attack towards the prey.

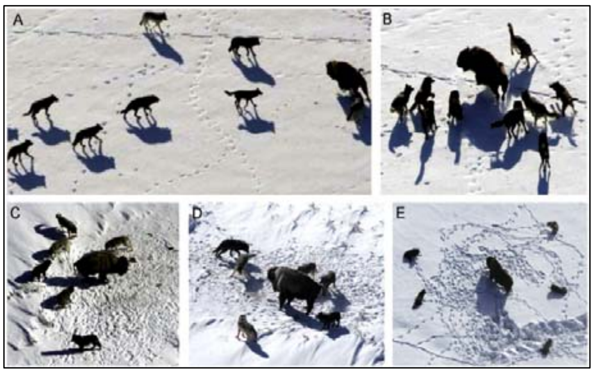


Fig.9.Hunting behavior of grey wolves: (A) chasing, approaching, and tracking prey. (B-C-D) pursuing, harassing, and encircling. (E) stationary situation and attack [38]

The GWO algorithm has many adherent advantages that can be summarized as follows:
1) It is a free-derivative algorithm;
2) It has lower parameters to be adjusted;
3) It has lower operators compared with other evolutionary algorithms;
4) It can preserve information about the search space with iterations and saves the best solution obtained;
5) It is simple and easy to implement [36].

Recently, the GWO algorithm has successfully been applied to several test functions and its results were promising compared with those of other optimization techniques [39].

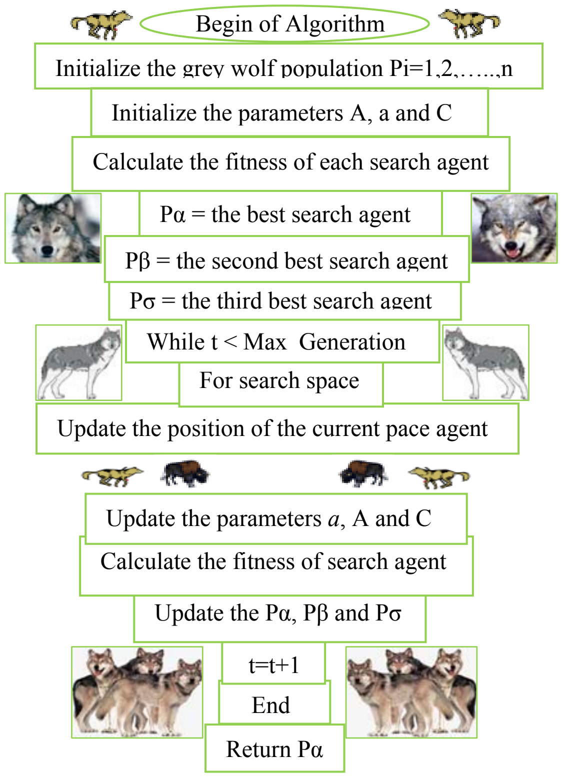


Fig.10.The process and pseudo code of the GWO.

The Strategy of the Grey Wolf Optimization (GWO)

The mathematical model of hunting mechanism of grey wolves consists of the following:

- Tracking the prey.
- Encircling the prey.
- Attacking the prey.

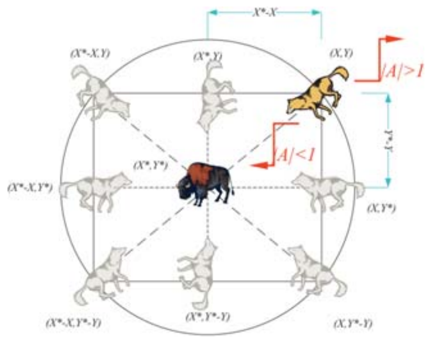


Fig.11.Position updating mechanism of search agents and effects of A on it [38]

1) Encircling prey: Grey wolves encircle prey during the hunt. In this process, a grey wolf can update its position inside the space around the prey in any random location by using (9) and (10). The encircling behaviour of grey wolves can be represented as: [39]

(9) $$\vec{D} = \left|\vec{C}\vec{P}^*(t) - \vec{P}^*(t)\right|$$

(10) $$\vec{P}(t+1) = \vec{P}^*(t) - \vec{A}\vec{D}$$

where t indicates the current iteration, $\vec{A}$ and $\vec{C}$ is coefficient, $\vec{P}^*(t)$ is the position vector of the prey, and $\vec{P}$ indicates the position vector of a grey wolf.

The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

(11)
$$\begin{cases} \vec{A} = 2\vec{a}\vec{r}_1 - \vec{a} \\ \vec{C} = 2\vec{r}_2 \end{cases}$$

where components of a are linearly decreased from 2 to 0 over the course of iterations and r_1 and r_2 are random vectors in [0, 1].

2) Hunting: Is usually guided by α and β, and δ will participate occasionally. The best candidate solutions, that is, α, β, and δ, have better knowledge about the potential location of prey. The other search agents (ω) update their positions according to the position of three best search agents. The following formulas are proposed in this regard:

(12)
$$\vec{D}_\alpha = \left|\vec{C}_1\vec{P}^*(t) - \vec{P}(t)\right|$$

(13)
$$\vec{D}_\beta = \left|\vec{C}_2\vec{P}_\beta^*(t) - \vec{P}(t)\right|$$

(14)
$$\vec{D}_\delta = \left|\vec{C}_3\vec{P}_\delta^*(t)\vec{P}(t)\right|$$

(15)
$$\vec{P}_1 = \vec{P}_\alpha^*(t) - \vec{A}_1\vec{D}_\alpha$$

(16)
$$\vec{P}_2 = \vec{P}_\beta^*(t) - \vec{A}_2\vec{D}_\beta$$

(17)
$$\vec{P}_3 = \vec{P}_\delta^*(t) - \vec{A}_3\vec{D}_\delta$$

(18)
$$\vec{P}(t+1) = \frac{\vec{P}_1 + \vec{P}_2 + \vec{P}_3}{3}$$

3) Attacking Prey: In order to mathematically model for approaching the prey, we decrease the value of. The fluctuation range of is also decreased by. Is a random value in the interval [$-a$, a] where a is decreased linearly from 2 to 0 over the course of iterations. When random values of are in [−1, 1], the next position of a search agent can be in any position between its current position and the position of the prey. The value |A| <1 force the wolves to attack the prey [40-41-42].

After the attack again they search for the prey in the next iteration, wherein they again find the next best solution among all wolves. This process repeats till the termination criterion is fulfilled [43].

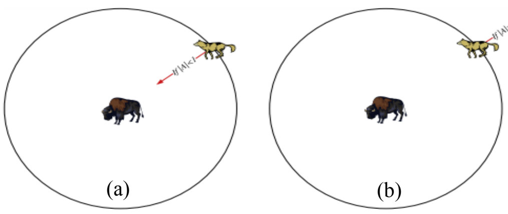


Fig.12.Exploitation and exploration characteristics of grey wolf: (a) Attacking prey (exploitation) and (b) Searching for prey (exploration) [38]

Simulation, Results and Discussion

The proposed methodology was simulated on a hybrid system (micro gas turbine/photovoltaic/wind turbine) in the real grid, Algerian site (Naama). The detailed data are presented in Table 4. Different scenarios are considered for this study. The wind and solar system are considered with a capacity of P_{Wind} = 100 [MW] and P_{solar} = 20 [MW].

The simulations were executed for three different scenarios:

Scenario 1: Economic dispatch with gas turbine and solar power.

Scenario 2: Economic dispatch with gas turbine and wind power.

Scenario 3: Economic dispatch with gas turbine, solar and wind power.

The simulation was performed under MatlabR2013asur Intel Core n(TM) processor i5-3230M CPU 2.60GHz, 4.00GB RAM. The maximum energy consumption of three large regions in state throughout the year 2018 is 221.336255 [MW].

Table 4.Cost Coefficients and Production Limits for an Electrical Network, Naama Site (SouthWest- Algerian)

Generator bus N°	Cost coefficients ($/h)			Generation limits(MW)	
	a_i	b_i	c_i	$P_{g,}^{min}$	$P_{g,}^{max}$
1_(Pg gas)	0.0085	0	0	80	300
2_(Pgsolar)	0.002	0	0	0	20
3_(Pgwind)	0.0021	0	0	0	180

Scenario 1: Economic Dispatch with Micro Gas Turbine and Solar Power.

To show the impact of solar power farm, it has been applied to economic dispatch problem on the power network, Naama site. The solar farm is designed with 10000 PV modules which comprise an installed capacity of 20 MW (10000*220W). Four seasons were taken in the optimization.

Table 5.Production Capability and Fuel Costs of Combined Gas Turbine and Solar Systems, Using GWO

Criterion	Base case	Winter	Spring	Summer	Autumn
$P_{g.gas}$ [MW]	222.0756	216.1838	209.5243	**203.7123**	212.5550
$P_{g.solar}$ [MW]	0	5.91	12.59	**18.42**	9.55
P_{Loss} [MW]	1.0756	1.0938	1.1143	1.1323	1.1050
P_{output} [MW]	222.0756	222.0938	222.1143	222.1323	222.1050
P_{demand} [MW]	221	221	221	221	221
Total cost [$/h]without **GWO**	419.1992	397.5616	374.5629	**355.7553**	384.2091
Total cost [$/h] with **GWO**	419.1992	357.4216	334.3729	**315.3153**	344.1271

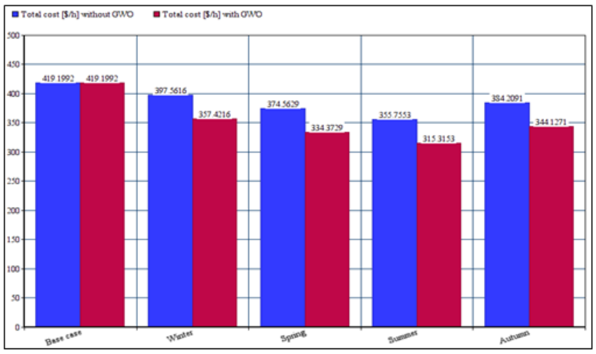


Fig.13.The charts of production capability and fuel costs of a combined Micro Gas Turbine and Solar systems without GWO, and with GWO.

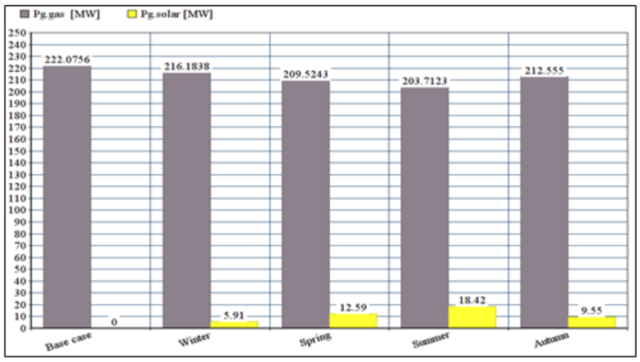


Fig.14.Contribution of Solar energy compared to Micro Gas Turbine during all seasons.

The results, including the optimal values of the generated power, generation cost, and power losses are reported in Table 5.

From Table 5, it is clear that the contribution from the solar power plant is considerable in summer season since the generation cost is less compared to the remaining cases. In addition, the profit obtained with the incorporation of solar farm is significant compared to the base case.

Scenario 2: Economic Dispatch with Micro Gas Turbine and Wind Power.

To assess the efficiency of the wind power plant, economic dispatch is carried out for the updated demand and the function is optimized and analyzed for four seasons. We deduced from Table III that a wind farm in Mecheria generating more than 100MW.

The power generated and fuel cost is given in Table 6.

Table 6.Production Capability and Fuel Costs of Combined Gas Turbine and Wind power Systems, Using GWO

Criterion	Base case	Winter	Spring	Summer	Autumn
$P_{g.gas}$ [MW]	223.0839	132.3532	**122.3841**	170	137.3377
$P_{g.wind}$ [MW]	0	90	**100**	55	85
P_{Loss} [MW]	2.0839	1.3532	1.3841	1.2713	1.3377
P_{output} [MW]	223.0839	222.3532	222.3841	225	222.3377
P_{demand} [MW]	221	221	221	221	221
Total cost [$/h]Without **GWO**	423.0146	165.9076	**148.3118**	252.0025	175.4966
Total cost [$/h] with **GWO**	423.0146	123.3184	**112.7289**	217.4196	122.9137

The contribution in each season of wind power plant is higher, compared to the case studies above in scenario 1, the price has clearly decreased. From this it is clear that installing wind farm in the location of (Mecheria) can reduce the generation cost.

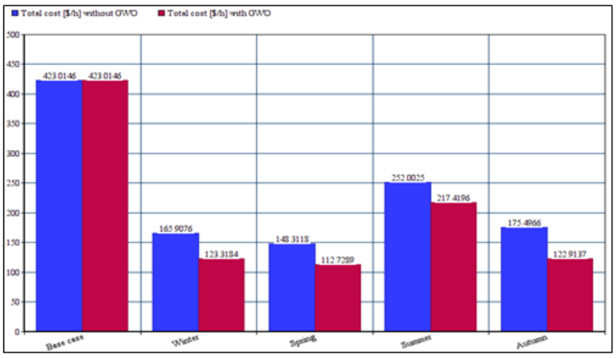


Fig.15.The charts of production capability and fuel costs of a combined Micro Gas Turbine and Wind power systems, without GWO, and with GWO.

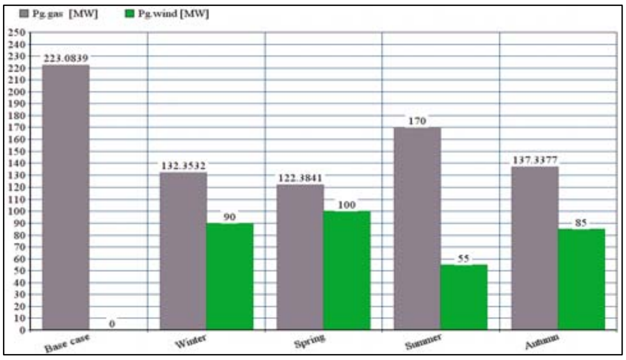


Fig.16.Contribution of Wind energy compared to Micro Gas Turbine during all seasons

Scenario 3: Economic Dispatch with Micro Gas Turbine, Solar and Wind Power.

In this case, it is assumed that the solar and wind farms are combined with a micro gas turbine, this is carried out similar to scenario 1 and scenario 2 above. Here the cost comparison for various seasons is presented in Table 7.

Table 7.Production Capability and Fuel Costs of Combined Micro Gas Turbine and Solar Systems and Wind Power Systems, Using GWO.

Criterion	Base case	Winter	Spring	Summer	Autumn
$P_{g.gas}$ [MW]	223.0839	125.4669	**108.5853**	148.3937	126.8711
$P_{g.solar}$ [MW]	0	5.91	**12.59**	18.42	9.55
$P_{g.wind}$ [MW]	0	90	**100**	55	85
P_{Loss} [MW]	2.0839	0.3769	0.1753	0.8137	0.4211
P_{output} [MW]	223.0839	221.3769	221.1753	221.8137	221.4211
P_{demand} [MW]	221	221	221	221	221
Total cost [$/h]Without **GWO**	423.0146	150.8864	**121.5385**	194.2069	152.1732
Total cost [$/h] with **GWO**	423.0146	102.3035	**83.9556**	121.6240	106.4942

These results show that the incorporation of solar and wind power plant into the system illustrated an optimal cost and is the most economical.

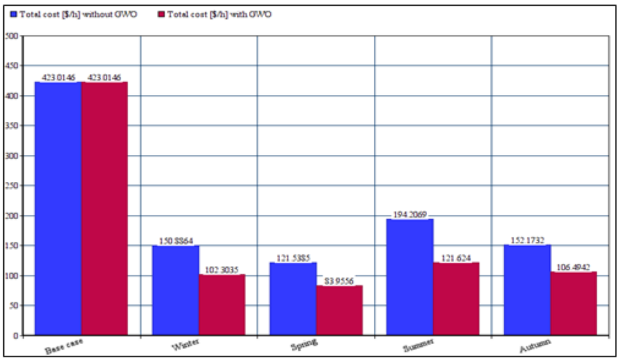


Fig.17.The charts of production capability and fuel costs of a combined Micro Gas Turbine, Solar energy and Wind power systems without GWO, and with GWO.

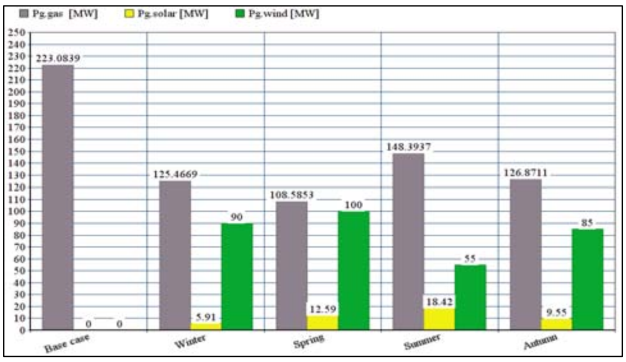


Fig.18.Contribution of Solar and Wind energy compared to Gas Turbine during all seasons

Incarnation of the behavior of GWO in the distributed network of the Naama site

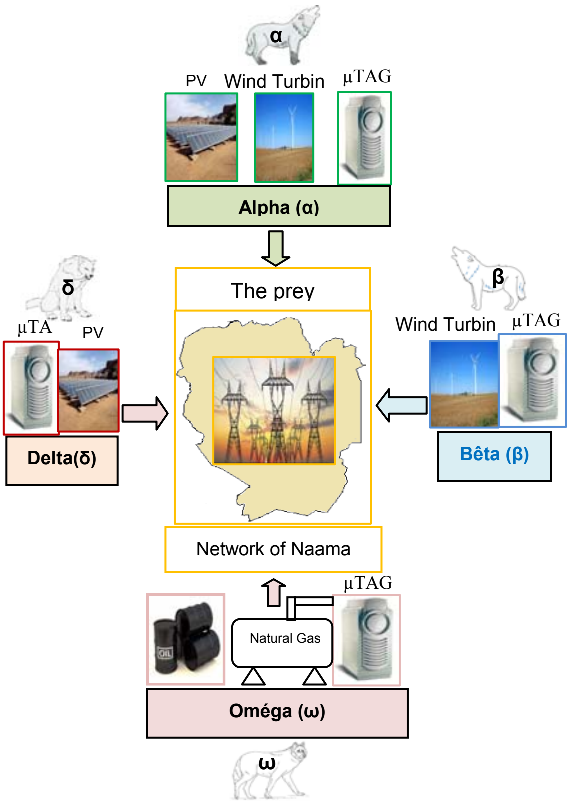


Fig.19.GWO strategy for attacking and choosing the most efficient energy source.

Conclusion

In this paper, the grey wolf optimizer (GWO) algorithm has been presented and applied to the total cost function of a system consisting of several power generation units (wind power, solar energy and gas turbine). The study proves the efficiency of renewable energies and its positive impact on modern power grid management.

Thus, we have concluded that the integration of renewable energies has a positive impact on the economic distribution, which will considerably reduce the losses of money compared to the traditional system, for Naama site, the wind system has a more favourable economic impact than that of solar energy.

So, hybridization of electrical generation plants in renewable energies, allows us to take advantage of two free sources to reduce the deficits of the Algerian system of electricity production. The results obtained in the studied case say that the addition of wind turbines reduces the fuel consumption in Naama site.

This study applied the new method grey wolf optimizer (GWO) to solve the optimal sizing of a hybrid (PV/Wind/Gas micro-turbine) system. The main objective of the optimization problem is to minimize the system total annual cost. The results showed that the method gives a better performance with optimal results in all cases and within the constraints imposed.

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