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.


Keywords: Economic dispatch – gray wolf optimizer (GWO) – hybrid power system – solar energy – wind energy.
Słowa kluczowe: optymalizacja, zintegrowania źródeł 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). 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)

Forms of renewable energies
Hydroelectric
Wind
Deep geothermal
Photovoltaic
Solar
Aérothe
biom
Surface geothermal

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:

\[ P_p = \eta \cdot A_p \cdot G_s \cdot (1 - \delta_T) \]

where \( \eta \) is the power generation efficiency of the PV, \( A_p \) refers to the solar irradiated while \( T_c \) represents the temperature coefficient. \( \delta_T \) 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:

\[ P_p = \int_{G_s} P_p \cdot f \cdot dG_s \]

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

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).

B. Wind Power

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].

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].
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 km² and a population of about 225530 either a density average of 7.6 inhabitants per km² (see Fig. 6). [29]

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]

<table>
<thead>
<tr>
<th>Stations</th>
<th>Ain-Sefra</th>
<th>Mecheria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Max (°C)</td>
<td>Min (°C)</td>
</tr>
<tr>
<td>January</td>
<td>11.6</td>
<td>4.3</td>
</tr>
<tr>
<td>February</td>
<td>20.2</td>
<td>1.5</td>
</tr>
<tr>
<td>March</td>
<td>26.6</td>
<td>16.9</td>
</tr>
<tr>
<td>April</td>
<td>16.9</td>
<td>7.2</td>
</tr>
<tr>
<td>May</td>
<td>26.5</td>
<td>15</td>
</tr>
<tr>
<td>June</td>
<td>33.1</td>
<td>18.6</td>
</tr>
<tr>
<td>July</td>
<td>39</td>
<td>24.4</td>
</tr>
<tr>
<td>August</td>
<td>34.7</td>
<td>21.3</td>
</tr>
<tr>
<td>September</td>
<td>31.2</td>
<td>17.4</td>
</tr>
<tr>
<td>October</td>
<td>26.3</td>
<td>17</td>
</tr>
<tr>
<td>November</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>December</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

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:

\[
\min \left[ \sum_{j=1}^{n_j} F_j(P_j) \right]
\]

where most often \( F_j(P_j) \) is a quadratic polynomial:

\[
F_j(P_j) = a_j P_j^2 + b_j P_j + c_j
\]

where \( F \) is the total fuel cost of the system, \( n_j \) is the number of generators, and \( a_j, b_j \) and \( c_j \) are the cost coefficients of the \( f^j \) generating unit, \( P_j \) real power generation, \( P_{\text{min}}^j \) and \( P_{\text{max}}^j \) are the minimum and maximum limits for the production of the \( f^j \) unit.

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

\[
P_L = \sum_{j=1}^{n_j} \sum_{k=1}^{n_k} P_{j,k} P_{j,k}^d + \sum_{j=1}^{n_j} B_{j,k} P_{j,k} + B_{0k}
\]

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 (\( a \)), beta (\( B \)), delta (\( \delta \)), and omega (\( \omega \)) 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 discipliner 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].

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.

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].

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.

The GWO algorithm begins with the wolves being randomly placed inside the search space. They are initialized by generating their position vectors, and each wolf is given an initial fitness value based on the objective function.

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]

\[ \bar{D} = |\bar{C} \bar{P}(t) - \bar{P}(t)| \]  
\[ \bar{P}(t+1) = \bar{P}(t) - \bar{A} \bar{D} \]

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

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]

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

Fig.11. Position updating mechanism of search agents and effects of \( \bar{A} \) on it [38]
The vectors $\vec{A}$ and $\vec{C}$ are calculated as follows:

$$\begin{align*}
\vec{A} &= 2\vec{a} - \vec{d} \\
\vec{C} &= 2\vec{r}_2
\end{align*}$$

where components of $\vec{a}$ 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 $\alpha$ and $\beta$, and $\delta$ will participate occasionally. The best candidate solutions, that is, $\alpha$, $\beta$, and $\delta$, have better knowledge about the potential location of prey. The other search agents ($\omega$) update their positions according to the position of the three best search agents. The following formulas are proposed in this regard:

$$\begin{align*}
\vec{D}_n &= |\vec{C}_n^j\vec{P}(t) - \vec{P}(t)| \\
\vec{D}_p &= |\vec{C}_p^j\vec{P}(t) - \vec{P}(t)| \\
\vec{D}_g &= |\vec{C}_g^j\vec{P}(t) - \vec{P}(t)| \\
\vec{P}_n &= \vec{P}_n^j - \vec{D}_n \\
\vec{P}_p &= \vec{P}_p^j - \vec{D}_p \\
\vec{P}_g &= \vec{P}_g^j - \vec{D}_g \\
\vec{P}(t + 1) &= \frac{\vec{P}_n + \vec{P}_p + \vec{P}_g}{3}
\end{align*}$$

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 approaching the prey, we decrease the value of. The value $|A| < 1$ force the wolves to attack the prey position between its current position and the position of the prey. The other search agents ($\omega$) update their positions according to the position of the three best search agents.

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].

**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 MatlabR2013a/sur 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].

**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>
<thead>
<tr>
<th>Scenario</th>
<th>Economic dispatch with Micro Gas Turbine</th>
<th>Solar Systems Using GWO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Economic Dispatch with Micro Gas Turbine</td>
<td>Solar Systems Using GWO</td>
</tr>
<tr>
<td>Winter</td>
<td>222.0756</td>
<td>216.1838</td>
</tr>
<tr>
<td>Spring</td>
<td>209.6243</td>
<td>203.7123</td>
</tr>
<tr>
<td>Summer</td>
<td>212.5550</td>
<td>18.42</td>
</tr>
<tr>
<td>Autumn</td>
<td>203.7123</td>
<td>11.143</td>
</tr>
<tr>
<td>Total cost [$/h] without GWO</td>
<td>419.1992</td>
<td>397.5629</td>
</tr>
<tr>
<td>Total cost [$/h] with GWO</td>
<td>355.7553</td>
<td>334.3729</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Generator bus No</th>
<th>Cost coefficients ($/h)</th>
<th>Generation limits (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>$a$</td>
<td>$b$</td>
</tr>
<tr>
<td>1 (Pg gas)</td>
<td>2.0085</td>
<td>0</td>
</tr>
<tr>
<td>2 (Pgsolar)</td>
<td>0.002</td>
<td>0</td>
</tr>
<tr>
<td>3 (Pwind)</td>
<td>0.0021</td>
<td>0</td>
</tr>
</tbody>
</table>

**Table 5** Production Capability and Fuel Costs of Combined Gas Turbine and Solar Systems, Using GWO
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>
<thead>
<tr>
<th>Table 6: Production Capability and Fuel Costs of Combined Gas Turbine and Wind Power Systems, Using GWO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
</tr>
<tr>
<td>$P_{gen}$ [MW]</td>
</tr>
<tr>
<td>$P_{gen}$ [MW]</td>
</tr>
<tr>
<td>$P_{loss}$ [MW]</td>
</tr>
<tr>
<td>$P_{output}$ [MW]</td>
</tr>
<tr>
<td>Total cost [$/h] Without GWO</td>
</tr>
<tr>
<td>Total cost [$/h] with GWO</td>
</tr>
</tbody>
</table>

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

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>
<thead>
<tr>
<th>Table 7: Production Capability and Fuel Costs of Combined Micro Gas Turbine and Solar Systems and Wind Power Systems, Using GWO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Criterion</strong></td>
</tr>
<tr>
<td>$P_{gen}$ [MW]</td>
</tr>
<tr>
<td>$P_{gen}$ [MW]</td>
</tr>
<tr>
<td>$P_{loss}$ [MW]</td>
</tr>
<tr>
<td>$P_{output}$ [MW]</td>
</tr>
<tr>
<td>Total cost [$/h] Without GWO</td>
</tr>
<tr>
<td>Total cost [$/h] with GWO</td>
</tr>
</tbody>
</table>

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.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.

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

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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