Management and technical economic analysis of a hybrid system (wind/diesel) in southern Algeria

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Abstract: The increase in energy sources using fossil fuels is the main source of pollution. Diesel power stations are adapted to remote sites of energy sources. From an economic and technical point of view the integration of a hybrid system is beneficial. In this situation, the combination of hybrid power system (wind-diesel-battery)-based renewable energy is a strategy for the use of three complementary sources that will be suitable for continuity of service, reducing energy costs, longevity of the generator and the elimination of part of the greenhouse gas, this is the reason that motivated us to develop this product that addresses the optimal management of the production of electronic system energy to weather conditions (wind speed, temperature, relief) and the technical and economic analysis to meet our energy requirements to reduce emissions of greenhouse gases.

Keywords: wind; hybrid system; modelling; rural electrification; energy management; fuel; cost; Algeria.


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1 Introduction

The electric power is an essential factor for the development and the evolution of the human societies that is also the field of the improvement of the living conditions and the development of the industrial activities. Although, the need of electricity is always increasing nowadays, and far from the use of polluting fossil energies like oil and the gas, several countries turned to the new form of energy known as ‘renewable energies’. Indeed, a true world challenge is being taken with serious today, as well as on the policy of reducing of the gas emissions for purpose of greenhouse, while bringing back them to a tolerable level according to the convention of Kyoto. The evolution of technologies of the components returns the conversion of these energies increasingly profitable and thus their uses economically become competitive compared to the traditional sources (Galdi et al., 2009). These energies are exploited in mono source or hybrid and mode autonomous or connected to the network (Merzouk and Merzouk, 2006; Stoyanov et al., 2007). The power plant by several sources must meet connection architecture. Similarly, proper management of production sources for the consumer to cover the energy needs of the facility and ensure optimal use of the energy produced. In this context, we propose a study for a judicious choice of the network architecture composed by an autonomous wind diesel generator and a storage battery.

After this introductory, Section 1, this article is organised as follows: Section 2 presents the problem of the production of electricity in Algeria by the group diesel. Section 3 presents policy implications. In Section 4, we show the wind resource in Algeria. Section 5 presents the component wind diesel generation system. Section 6 shows the modelling of the wind diesel hybrid system (WDHS) components. Section 7 presents the control strategy of the isolated hybrid system. Section 8 presents the simulation and results. Conclusions have been made in Section 9.

2 Problems of the production of electricity by a diesel group

The Algerian network consists of an interconnected network in the north and more isolated networks are built around generating systems based on diesel generators to the South. The diesel generating fleet is distributed through the south of the country on more than 22 sites (see Figure 1). Diesel power stations are located in inaccessible areas, making it difficult fuel supply (see Table 1), moving the staff for operation and maintenance. This is why the use of diesel generators combined with a source of renewable energy and a storage system are recommended. It is with this objective that fits my article with the use of multiple sources for energy supply of the appropriate system.
Figure 1  Distribution of diesel generators in remote Algeria in the regions (see online version for colours)

Table 1  Supply fuel

<table>
<thead>
<tr>
<th>Central</th>
<th>Supply distance (Km)</th>
<th>Number of rotation of trucks per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>TINDOUF</td>
<td>2,000</td>
<td>35</td>
</tr>
<tr>
<td>TAMANRASSET</td>
<td>1,600</td>
<td>54</td>
</tr>
<tr>
<td>DJANET</td>
<td>1,620</td>
<td>14</td>
</tr>
<tr>
<td>B.EL HAOUES</td>
<td>1,500</td>
<td>2</td>
</tr>
<tr>
<td>IN GUEZZAM</td>
<td>2,000</td>
<td>4</td>
</tr>
</tbody>
</table>

3 Policy implications

Algeria is a vast country with gas and petroleum the rising price of oil in the world will not necessarily encourage the use of renewable energies. However, the signing of the Kyoto agreements by Algeria and the emergence of environmental problems have a government program which was set up to boost investment in the field of power generation from wind energy for 3% of the national balance sheet for 2027. Knowing that the energy resources of Algeria have been estimated by the Renewable Energy Development Centre (REDC) since the ‘90s.

In this context, Algeria can be among the countries using major sources of renewable energy in the world with all its essential elements in this context, especially as the global perspective today on the search for alternative sources energy from traditional sources tends towards the exploitation of wind as an energy source and a number of other energy sources like the sun and the water, thus Algeria is naturally is concerned by such sources, especially wind.
4 Wind speed in Algeria

The wind resource in Algeria varies greatly from one place to another. This is mainly due to a highly diversified topography and climate. Table 2 shows the wind speed in different regions of Algeria. Average annual rates obtained vary from 1.9 to 6.3 m/s. Note that regions in southern Algeria (Adrar, H’Rmel, ...) are characterised by higher wind speeds than the north, particularly in the region of Adrar that they exceed the value of 6 m/s; on the contrary the regions in the North (Algiers, Jijel), we notice that overall the average speed is low.

Table 2  Monthly and annual averages of wind speed in different site in Algeria (m/s)

<table>
<thead>
<tr>
<th>Site</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Yearly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adrar</td>
<td>6.2</td>
<td>6.4</td>
<td>6.5</td>
<td>6.5</td>
<td>6.9</td>
<td>6.1</td>
<td>6.7</td>
<td>6.2</td>
<td>6</td>
<td>5.8</td>
<td>5.9</td>
<td>5.8</td>
<td>6.3</td>
</tr>
<tr>
<td>Algiers</td>
<td>2.2</td>
<td>2.2</td>
<td>2.2</td>
<td>2.1</td>
<td>1.9</td>
<td>1.8</td>
<td>1.6</td>
<td>1.5</td>
<td>1.4</td>
<td>1.6</td>
<td>1.9</td>
<td>2.4</td>
<td>1.9</td>
</tr>
<tr>
<td>HR’mel</td>
<td>5.7</td>
<td>6.3</td>
<td>7.6</td>
<td>8.1</td>
<td>7.8</td>
<td>6.6</td>
<td>5.3</td>
<td>5.4</td>
<td>4.8</td>
<td>4.5</td>
<td>5.7</td>
<td>6.1</td>
<td></td>
</tr>
<tr>
<td>Jijel</td>
<td>2.6</td>
<td>2.9</td>
<td>3.3</td>
<td>2.8</td>
<td>2.1</td>
<td>2.1</td>
<td>2.2</td>
<td>2</td>
<td>2.1</td>
<td>2.2</td>
<td>2.5</td>
<td>3.1</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Source: Chellali et al. (2011)

5 Schematic of the isolated power system

Figure 2 shows a remote area power system and its components. The WDHS presented in this article consists of a diesel engine (DE), a synchronous machine (SM), a wind turbine generator (WTG), the consumer load (PL), a (Ni-Cd) battery based on energy storage system (BESS) (Sebastian, 2011).

Figure 2  Renewable generation hybrid system (see online version for colours)

The connection of these elements is produced at a DC bus. This bus has the advantage of more easily interconnect the various components of the hybrid system from the DC bus the network connection is achieved through a DC/AC power converter which adjusts the
voltage and frequency before it is transformed into the AC power to be transmitted to the loads (PL).

Power management of the different sources is ensured by controlling the opening and closing manager of different power electronic switches according to the strategy indicated in Section 7.

This system is classified as being high penetration (HP) as shown in Figure 3. Hybrid wind-diesel systems with high penetration of wind power (HWDS-HP) have three plant modes: diesel only (DO), wind-diesel (WD) and wind only (WO).

**Figure 3** Variation of energy covered by a system wind-diesel and diesel consumption as a function of wind speed (see online version for colours)

We studied in this article, the energetic modelling study of a comprehensive model of a hybrid system (wind-diesel), this system is based on the new strategy in energy management providing timekeeping hybrid system the objectives of this article are:

- insurance of continuity of electric service
- the availability of wind source (free and inexhaustible)
- the protection of the environment, particularly in terms of reducing CO₂ emissions
- the reduction in fuel consumption.

6 **Modelling of sources**

6.1 **Modelling of the turbine of the wind**

Generator wind farm, consisting of a turbine at variable speed coupled with a synchronous generator with permanent magnets through a multiplier.

6.1.1 **Model wind**

The wind speed is usually represented by a scalar function that evolves over time.

\[ V_c = f(t) \]  

(1)
The wind speed will be modelled in this part, as deterministic as a sum of several harmonics (Slotine and Li, 1991):

\[ V_t = A + \sum_{n=1}^{N} a_n \sin(b_n W_t) \]  

(2)

### 6.1.2 Model of the turbine

Applying the theory of momentum and Bernoulli, we can determine the incident power (theoretical) due to wind (Alesina and Venturini, 1988; Seyoum et al., 2003):

\[ P_{\text{incident}} = \frac{1}{2} \rho S V^3 \]  

(3)

- \( S \) the area swept by the blades of the turbine surface [m²]
- \( \rho \) the density of the air [\( \rho = 1.225 \text{ (m}^3\text{/kg)} \) at atmospheric pressure]
- \( V \) wind speed [m/s].

In wind energy system due to various losses, provided on the power extracted from the turbine rotor is less than the forward power. The power extracted is expressed by the following formula:

\[ P_{\text{extraite}} = \frac{1}{2} \rho S C_p(\lambda, \beta) V^3 \]  

(4)

- \( C_p(\lambda/\beta) \): power coefficient, which expresses the aerodynamic efficiency of the turbine. It depends on the ratio \( \lambda \), which represents the ratio between the speed at the tips of the blades and the wind speed, and the angle of orientation of the blades \( \beta \). The ratio \( \lambda \) expressed by the following formula:

\[ \lambda = \frac{\Omega_R}{v} \]  

(5)

The maximum power coefficient \( C_p \) was determined by Albert Betz as follows (Budinger et al., 2000):

\[ C_p^{\text{max}}(\lambda, \beta) = \frac{16}{17} \approx 0.939 \]  

(6)

The power factor is the aerodynamic efficiency of the wind turbine. It depends on the shape of the turbine rotor and the angle of orientation of the blades \( \beta \) and the ratio of the speed \( \lambda \). This coefficient can be written as follows:

\[ C_p(\lambda, \beta) = 0.5176 \left( \frac{116}{\lambda i} - 0.4 \beta - 5 \right) \left( \frac{21}{\lambda i} \right) + 0.0068 \lambda i \]  

(7)

with

\[ \frac{1}{\lambda i} = \frac{1}{\lambda + 0.08 \beta - \beta^3 + 1} \]  

(8)
Figure 4 illustrates the curves of the power coefficient as a function of $\lambda$ for different values of $\beta$.

**Figure 4**  Power coefficient $C_p(\lambda / \beta)$ versus $\lambda$ (see online version for colours)

The aerodynamic torque on the output shaft can be expressed by the following formula:

$$C_{al} = \frac{P_{tot}}{\Omega_t} = \frac{1}{2} \rho S C_p(\lambda, \beta) V^3 \frac{1}{\Theta_t}$$  

(9)

$\Omega_t$  rotational speed of the turbine

$C_{al}$  torque on the slow axis (turbine side).

6.1.3 Model multiplier

The multiplier is characterised by its gain ‘$G$’. It adjusts the speed of rotation ($\Omega_t$) of the turbine to the generator speed $\Omega_g$:

$$C_{avr} = G \ast C_g$$  

(10)

6.1.4 Tree model

The basic equation of dynamics applied to the shaft of the generator determines the evolution of the mechanical speed $\Omega_m$ from the total mechanical torque $C_m$:

$$C_m = J \frac{d\Omega_m}{dt}$$  

(11)

$J$  total inertia that appears on the rotor of the generator:

$$J = \left( \frac{J_t}{G^2} \right) + J_g$$  

(12)
with

\[ J_g \] the inertia of the generator

\[ J_t \] the inertia of the turbine.

The above equations are used to establish the servo block diagram of the turbine speed (see Figure 5).

**Figure 5** PMSG speed control loop (see online version for colours)

To capture the maximum power of the incident wind, it is recommended to adjust the rotational speed of the wind turbine. Optimal mechanical turbine speed is \( \lambda_{\text{opt}} \) and \( \beta = 0^\circ \). The speed of the permanent magnet synchronous generator (PMSG) is used as a reference for a controller proportional-integral type (PI phase lead). It may be determined that the control target is the electromagnetic torque that should be applied to the machine for rotating the generator at its optimum speed. The couple that is determined by the controller is used as a reference torque of the turbine model (see Figure 5). Variation of the system of the orientation angle of the blades (variation of the angle of incidence) to change the ratio between the lift and drag. To extract the maximum power (and keep constant), we adjust the angle of the blades to the wind speed.

### 6.1.5 Modelling of permanent magnet synchronous machine

Current machines alternating are generally modelled by equations nonlinear (differential equations). The nonlinearity is due to the inductance and coefficients of the dynamical equations which depend on the rotor position and time. In this article it is based on simplifying assumptions the model of the MAS becomes relatively simple.

After simplifications there (Hunter and Elliot, 1994):

\[
V_d = R_d i_d + L_d \frac{di_d}{dt} - \psi_q w_r
\]

\[
V_q = R_s i_q + L_q \frac{di_q}{dt} + \psi_d w_r
\]  

\[ (13) \]
With
\[ \psi_d = L_d i_d + \psi_f \]
\[ \psi_q = L_q i_q \]
(14)
\[ \psi \] flow of permanent magnets.

The relationship (13) becomes
\[ V_d = R_d i_d + L_d \frac{di_d}{dt} - L_q i_q \omega_r \]
\[ V_q = R_q i_q + L_q \frac{di_q}{dt} + (L_d i_d + \Phi_f) \omega_r \]
(15)

The general expression of the electromagnetic torque and after simplification can be found:
\[ C_{em} = P \left( \phi_d i_q - \phi_q i_d \right) \]
(16)

By replacing \( \phi_d \) and \( \phi_q \) with their values is:
\[ C_{em} = P \left( (L_d - L_q) i_d + \phi_f \right) i_q \]
(17)

The mechanical equation is written:
\[ J \frac{d\Omega}{dt} + f \Omega = C_{em} - C_r \]
(18)
\[ \Omega = \frac{\omega_r}{P} \]
(19)

With angular velocity \( \omega_r \) (electric pulse).

The permanent magnet synchronous machine (PMSM) is used in most conventional methods of electricity production. A PMSG is used to convert the mechanical energy of the wind into electrical energy.

6.2 Diesel generator

The generator consists of a diesel engine and a synchronous machine. The diesel engine produces mechanical energy by combustion of fuel. Synchronous generator converts mechanical energy into electrical energy (Tudorache and Roman, 2010). The frequency is regulated through regulation of the speed of the diesel engine, as the amplitude is controlled into the excitation of the synchronous machine (Chedid et al., 2000).

Instant fuel consumption \( \text{Consu}_{\text{fuel}} \) of the generator depending on the instantaneous power supplied PDG is given by the following equation:
\[ \text{Consu}_{\text{fuel}} = \text{Consu}_{\text{fuel}, \text{speci}} + \text{Consu}_{\text{specific, fuel}, \text{DG}} P_{\text{DG}} \]
(20)
Management and technical economic analysis of a hybrid system

6.3 Storage system modelling

There are three types of battery models reported in the literature, specifically: Experimental, electrochemical and electric circuit-based. Experimental and electrochemical models are not well suited to represent cell dynamics for the purpose of state-of-charge (SOC) estimations of battery packs. However, electric circuit-based models can be useful to represent electrical characteristics of batteries. The simplest electric model consists of an ideal voltage source in series with an internal resistance. In this work, a generic battery model suitable for dynamic simulation presented in Chan and Sutanto (2000) is considered. This model assumes that the battery is composed of a controlled-voltage source and a series resistance, as shown in Figure 6. This generic battery model considers the SOC as the only state variable (Ding et al., 2010).

Figure 6  Generic battery model

\[
\begin{align*}
E &= E_0 - \frac{V_p Q_b}{Q_b - \int i_b dt} + \tilde{A} \exp\left(-B_i \int i_b dt\right) \\
&= E_0 - \frac{V_p Q_b}{Q_b - \int i_b dt} + \tilde{A} \exp\left(-B_i \int i_b dt\right)
\end{align*}
\]

when \( E \) is the battery constant voltage (V), \( E_0 \) is battery constant voltage (V); \( V_p \) is the polarisation voltage (V), \( Q_b \) is the battery capacity (AH), \( i_b \) is the battery current (A); \( \tilde{A} \) is exponential zone amplitude (V), \( B_i \) is exponential zone time constant inverse (AH^{-1}). The SOC of the battery is zero when the battery is empty and 100% when is fully charged and is calculated as (Sebastián, 2013):

\[
SOC = 100 \left(1 - \frac{1}{Q} \int i_b dt\right)
\]

Under Matlab/Simulink environment, the battery block, used in this study, is of nickel-cadmium (Ni-Cd) type (see Figure 7).
6.4 Model of the inverter PWM

6.4.1 Structure three levels inverter

The inverter on three levels is composed of three arms and two sources of tension. Each arm of the inverter consists of four pairs of bidirectional diode-switch and two median diodes. This makes it possible to have level zero of the output voltage of the inverter. The middle point of each arm is connected to a DC supply following Figure 8 giving the following schematic representation.

Figure 8 The inverter structure three levels
6.4.2 Control of static converters

A converter is said to order mode if the transitions between its different configurations only depend on the external command and no longer the internal commands.

6.4.2.1 Additional order

To prevent short circuits of the conduction voltage sources and to deliver the three desired voltage levels we must operate in its control mode.

Table 3 Excitation of switches

<table>
<thead>
<tr>
<th>$G_{k1}$</th>
<th>$G_{k2}$</th>
<th>$G_{k3}$</th>
<th>$G_{k4}$</th>
<th>$V_{ko}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>$V_{c2}$</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>Unknown</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>$V_{c1}$</td>
</tr>
</tbody>
</table>

Three additional commands can be applied on an arm of ups at three levels.

$$
\begin{align*}
G_{k3} &= \overline{G}_{k1} \\
G_{k4} &= \overline{G}_{k2} \\
G_{k5} &= \overline{G}_{k3} \\
\end{align*}
$$

(23)

with $G_{k}$ is control switch arm $k$ and $T_{k}$ is trigger.

In order to have full control of the three levels inverter, we must eliminate the case which gives an unknown response. By translating this additional order with the connection of the arm ‘$k$’ switches functions, can be found:

$$
\begin{align*}
F_{k1} &= 1 - F_{k4} \\
F_{k2} &= 1 - F_{k5} \\
\end{align*}
$$

(24)

We define the function of connection of the semi-arm noted $F_{km}$ with:

$$
m = \begin{cases} 
1 & \text{for the half arm top made up of } TD_{k1} \text{ and } TD_{k2} \\
0 & \text{for the half arm top made up of } TD_{k3} \text{ and } TD_{k4}
\end{cases}
$$

Connection of the semi-arm functions are expressed using functions of the switches as follows:

$$
\begin{align*}
F_{k1}^{b} &= F_{k1}F_{k2} \\
F_{k0}^{b} &= F_{k3}F_{k4} \\
\end{align*}
$$

(25)

7 System operation strategies

Good management system (WDHS) should ensure both safety and good performance of the operation of the facility; this is why the constraints of individual system components must be taken into account in the management system strategy. For a multi-source energy system, a power flow management strategy is needed. According to wind speed values
\( (V_m) \) and the power demanded by the consumer load. The power system has three operation modes, as follows (Ibrahim et al., 2011).

- weak winds \( (V_m \leq 3) \) m/s : (DO) in service
- moderate winds \( (3 < V_m \leq 10) \) m/s : (WD) in service
- strong winds \( (10 < V_m \leq 17) \) m/s : (WO) in service.

To adapt the production of the renewable source to the need for the load, we integrate a system of storage, such as the battery (BESS) to ensure the continuity of service; that is necessary to feed the load, in case when the generator diesel fails and the wind is insufficient (low) for the operation of the wind turbine.

The power management strategy used in this study is according to Figure 9:

**Figure 9** Main flow chart
8 Results and discussions

To reveal the selection of good sites for implementation of this system in Algeria, we should have to choose the place that takes into account with the following parameters (wind speed, power demanded). In this study (Aguglia et al., 2010), the geographic location is considered the city of Adrar (Figure 1) south west Algeria with following coordinates: Longitude 0.28; Latitude 27.82 and an aggregate area of 427,968 Km². The majority of sites in the city of Adrar could be considered remote sites view that its area is huge and their distance from each other. The extremely difficult weather conditions are another parameter to be taken into account. All this leads us to think about the integration of hybrid systems for supplying this remote area.

The Matlab-Simulink (The MathWorks, Inc.) model of the WDHS of Fig. 2 is shown in Figure 10.

Figure 10  Renewable generation hybrid system (WDHS) (see online version for colours)

Figure 11  Daily distribution of electrical charge (see online version for colours)

Electrical load demand is an important element of a WDHS and any other power generating system. The daily consumption is assumed to be following the same profile over all the year with peak load as 99 kW and is shown in Figure 11. It shows that the consumption is important in the daytime (99 kW with 12h and 13h) and negligible at
night (25 kW with 3h). It peaks at three points: at the early morning; at noon and at the beginning of the night as all the family members are around.

In this study, we seek to highlight the importance of the wind in the operation of the hybrid power system (WDHS) even to its role in reducing greenhouse gas emissions and global warming characterising the economic effect. Through the reduction of fuel consumption rate and the price which justifies reason of section studied. In this article we have studied the comparison of two months from the same region, the first month is characterised by a high ventilation rate (May) and the second month low ventilation (October).

Figure 12 represents the true wind speed measured in the city of Adrar for a year according to Table 2.

**Figure 12** The average yearly wind speed for the studied site (Adrar) (see online version for colours)

Figure 13 and Figure 14 represent the actual daily wind speed for the months of May and October respectively of the city of Adrar.

**Figure 13** The average daily wind speed in May (see online version for colours)
Figure 14  The average daily wind speed in October (see online version for colours)

Figure 15 and Figure 16 show the daily power generated by the system (WDHS) according to wind speed for two months; May and October.

Figure 15  Daily power generated by WDHS in May (see online version for colours)

Figure 16  Daily power generated by WDHS in October (see online version for colours)
According to Figure 15, we note that during the days (3rd, 13th, 17th, 25th) power consumers (PL) are fed by the electric power generated by WTG because of the excellent wind speed exceeding \( (V_{\text{m}} \geq 10 \, \text{m/s}) \) where these days the DG is at rest, while the surplus of the electric power is stored in the batteries for it to be used to rescue the system according to the strategy of the energy proposed in Figure 9. On the other hand, for days and particularly (7th, 22th) of the month, consumers are supplied by the DG due to weak wind rate \( (V_{\text{m}} \leq 3 \, \text{m/s}) \).

We notice in Figure 16, customer supply (PL) is generally provided by the diesel generator only (DO) where it works for the entire month. We also observe that wind has stopped working for five days during the months of October and particularly (1st, 3rd, 7th, 12th, 17th). On the other hand the month of May, it stopped for two days (7th, 22th), while the remaining days we use hybridisation (WD). Figure 17 represents the relationship of the daily consumption of fuel depending on the power generated by DG during the months of May and October respectively.

**Figure 17** Daily fuel consumption depending on the power generated by DG (see online version for colours)

According to Figure 17, the quantity of the fuel consumption is zero during the day (3rd, 13th, 17th, 25th) because the wind speed is sufficient. On the other hand for days (7th, 22nd), the fuel consumption is maximal view that the site is too windy during this time.

Figure 18 presents the quantity of fuel saved for two months. Knowing that fuel consumption is higher on October than in May.

**Figure 18** Gain of the fuel saved (see online version for colours)

Figure 19 shows the fuel consumption effect generated by DG on \( \text{CO}_2 \) emissions.
After comparing, we note that the CO$_2$ emission is higher in October corresponding to a volume of 1,779.2 emission (l/month), by what the DG generally provides power to the load (DO or DW). On the other hand for the month of May the total CO$_2$ pollution value is 1,280.7 (l/month).

The histogram of Figure 20 gives us a general idea about the total cost of kWh provided by the SWDH system for a month. Knowing that in the month of May the energy provided by the WTG is higher than DG which corresponds to the costs of 13,918 (DA/month) for wind and 7,131 (DA/month) for diesel, this will have a direct influence on the CO$_2$ emission rate and climate change.

In Table 4, we provide a summary of the daily calculations of economic costs generated by the system under study; knowing that the average price of electric energy consumption is 6.123 (DA/kWh) according to the source records SONELGAZ ‘The Algerian Society of Electricity Transmission System Management’.

To simulate the WDHS system, we have performed the simulation diagram in Figure 10 under the MATLAB/Simulink for supplying a load (AC) to a low voltage system knowing that at the beginning we use WO to power this load with a well-controlled wind speed. After we use DO generator for the same load. The synchronisation will be established between the two sources of energise at $t = 1.2s$ with a wind velocity ranging from 3 to 10 (m/s) (see Figure 21, Figure 22, Figure 23, Figure 24, Figure 25 and Figure 26).
A. Ksentini et al.

Table 4

Daily summary calculations of economic costs generated by the system studied

<table>
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<tr>
<th>Days</th>
<th>DG energy price (6.123 DA/kWh)</th>
<th>Fuel consumption (l/24h)</th>
<th>Unit fuel prices (14.2 DA/l)</th>
<th>CO₂ emission (2.71 kg/l)</th>
<th>Energy prices WTG (6.123 DA/kWh)</th>
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Figure 21  The evolution of the stator voltages: $WTG\ [10 \leq V_m < 17] \text{ (m/s)}$ (see online version for colours)

Figure 22  Voltages produced by DG: $[V_m < 3] \text{ (m/s)}$ (see online version for colours)

Figure 23  Currents produced by DG/WTG: $[3 \leq V_m < 10] \text{ (m/s)}$ (see online version for colours)

Figure 24  Overview of frequency (see online version for colours)
According to Figure 21, representing the three-phase simple tensions where the feeding of the consumers is only assured by the wind generator (WO), when the speed of the wind is included \([10 \text{ m/s with } 17 \text{ m/s}]\) until the time \((t = 1.2 \text{ s})\) according to the condition of adapted management; for this mode, I note that a surplus of wind power which can be stored in the battery with a system of regulation to ensure the continuity of service: this is necessary to feed the load of which in the case when the power generator unit falls down and the wind insufficient for operation (see Figure 25 and Figure 26). In the case where \((t \geq 1.2 \text{ s})\) the DG ensures only the feeding of the load concerned, knowing that the speed of the wind is lower than 3 m/s (see Figure 22).

9 Conclusions and perspectives

In this article, we have sized the integration of a hybrid system with a storage system located in a remote site. The hybrid system includes a wind turbine at variable speed controlled by the control maximum power point tracking (MPPT), a diesel generator and battery as an electrochemical storage system providing an essential role in the system studied. In this application, we have opted for the WDHS system located in the remote region of the city of Adrar, in the technical-economic study, we study the actual cost of fuel. Energy sources are connected to a bus (DC), under the MATLAB/Simulink environment. The results of our study have shown that the strategy we have proposed is profitable according to the configuration that have been used to help us gain an economic and technical as well as durability of our system. In addition, there is a continuous
insurance of service and the elimination of part of the greenhouse gas when operating in wind. To have a permanent solution in power problems in isolated perspective (technical, economic and environmental) in Algeria the country is moving towards a new form of energy called ‘renewable energy’ by launching an ambitious program of these energies and including energy efficiency will have a strategic role. The program is to establish a renewable power in the order of 22,000 MW between 2011 and 2030 to face national demand for electricity. In this context, the city of Adrar has received a draft wind farm power generation capacity of 10 MW, the first of its kind nationally and 2020, the province of Adrar will be reinforced with a new 175 MW power plant which is in progress, and whose studies are in progress, too.

References


Catalogue SONELGAZ, Algerian Management Company of Electricity Transmission System, specialised energy operator in the electricity generation, distribution and customer services, Algeria.


