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Energy Efficiency of an Autonomous Hybrid Energy System (PV/Wind)



Abstract: - This article deals with the energy efficiency of an autonomous hybrid electricity production system (PV / wind) power source for a typical household in an isolated village in Adrar Algeria. **The novelty** of this work is the study of the impact of building energy efficiency on the battery life of an autonomous hybrid energy system (PV-wind-battery). Purpose. In this study, we focus on the most important element of the energy source of the standalone hybrid energy system (PV-wind-battery) which is the battery. From the technological point of view for the choice of storage bank is the requirement of a low rate of battery aging in order to extend the battery life, which contributes to a reduction in the overall cost of the system over service life due to the need to replace the battery often. Due to the inability to meet the needs demanded by random load profiles, we have incorporated a complementary approach to home insulation to significantly improve energy efficiency. In order to improve the thermal comfort of the house and reduce the energy consumed by air conditioning and heating, a thermal and energy study on this house has been evaluated using TRNSYS 18 simulation software for the overall thermal and energy behavior of a habitat and its environment in dynamic regime (Numerical model type 56). **Results.** The simulation results show that the thermal insulation of the walls minimizes energy consumption by 13.39% in the case of heating and by 10% in the case of air conditioning. If we assume that a 10% decrease in energy needs for heating and air conditioning by the use on this typical house in the Adrar region, we observe its positive effect on optimizing of the lifetime of battery.

Keywords: Autonomous Hybrid system, energy efficiency, TRNSYS, building energy efficiency, thermal comfort

1. INTRODUCTION

Most isolated sites around the world are powered by autonomous decentralized electricity production systems. These generators use local renewable energy sources. Like photovoltaic panels, wind turbines and micro-turbines. Electricity from renewable sources is intermittent and depends on weather conditions.

These renewable generators are coupled to a storage system ensuring continuous availability of energy. for our study The renewable generators selected is a hybrid system (PV / wind) with storage. Generally, the storage is ensured by batteries which are currently one of the most used solutions. The batteries have very good yields, around 80-85%, and a very competitive price, if we consider lead technology.

The high demand for electrical energy used for air conditioning in isolated hot areas and for heating in isolated cold areas due to climate change, this negatively influences the operation of the decentralized electricity production system, particularly the storage system.

The building sector is very energy-intensive and is a major consumer of energy in the world, in Algeria. According to the National Agency for the Promotion and Rationalization of Energy Use (APRUE), energy consumption in the residential sector exceeds 43% of final energy. Around 43% of the final electrical energy consumed is used for air conditioning.

Faced with this problem, a study of the energy efficiency of the building is necessary.

The objective of this article is the study of the energy efficiency of an isolated habitat powered by an autonomous hybrid electricity production system (PV / wind), in order to reduce energy consumption for heating (in winter) and air conditioning (in summer), improve thermal comfort, guarantee the health of the accumulators and ensure a longer battery life and a minimum aging rate from a study of its state of charge (SOC). This work is a continuation of the previous study on the optimal sizing of an autonomous hybrid energy system (PV-wind-battery) as an energy source for a typical household in an Algerian village [1].

In order to improve energy efficiency and thermal comfort, to limit heat loss in winter and to avoid high temperatures in summer while reducing the energy consumed. This study aims to introduce insulating materials into a home

Several thermal insulation solutions have been proposed in the literature [2][3][4] in order to ensure excellent thermal comfort of a home and to minimize energy needs while improving energy efficiency in our work we are interested in thermal insulation of walls by interior because it is the simplest and most common solution to take into account the aesthetic and decorative aspect. TRNSYS software allows the user to construct multi-zone building models and choose the materials for the layers constituting the wall from an

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existing library. The thermo-physical characteristics of each layer (thickness, density, thermal conductivity, etc.) are defined by the user through the TRNBuild interface.

II. MODEL OF THE HYBRID SYSTEM COMPONENTS

The solar - wind hybrid energy production system consists of a photovoltaic generator, a wind turbine, a storage battery bank, AC / DC converters, DC / DC converters, a controller and cables (**Figure 1**). In order to predict the performance of the hybrid system, the individual components must first be modeled.

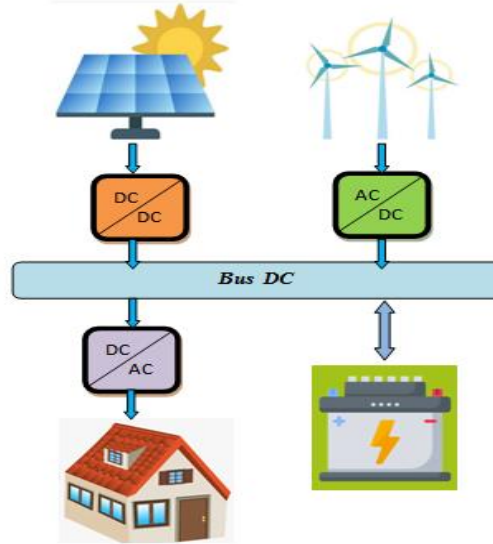


Figure 1 Block diagram of the hybrid system

The power delivered by the different energy sources depends on several parameters.

For the solar generator, the parameters influencing the power supplied by the generator are:

- The metrological data of the site: ambient temperature (T_a) and irradiation (I_r);
- The A_{pv} surface of the solar panel field.

For the wind generator, the power supplied is influenced by:

- The metrological data of the site: The ambient temperature T_a and the wind speed w_s ;
- The surface swept by the rotor of the wind turbine A_{wt} ;
-

A. Modeling of PV System

The model of the solar generator is given by the following expression [5,6,7]:

$$P_{pv}[W/m^2] = \eta_G A_{pv} I_r \quad (2.1)$$

With :

η_G : The overall efficiency of the generator given by the following equation:

$$\eta_G = \eta_r \eta_{pv} [1 - \beta_t (T_c - T_{NOCT})] \quad (2.2)$$

Where

η_r : The reference efficiency of the solar generator.

η_{pv} : The degradation factor of the solar generator according to its lifetime.

β_t : The coefficient of the influence of the temperature of the photovoltaic cells on the efficiency of the generator.

The temperature C ($^{\circ}C$) of the junction or the cell of the photovoltaic panel is given by:

$$T_c = 30 + 0.075(300 - I_r) + 1.14(T_a - 25) \quad (2.3)$$

T_{NOCT} : Nominal Operating Cell Temperature.

I_r : Irradiation or solar sunshine.

B. Modeling of the wind generator

The power model of the wind generator is given by the following expression (2.4)(2.5)[5][8][9]:

$$P_{wg} = \frac{1}{2} C_p \eta_{gb} \eta_g \rho A_{wt} w_s^3 \quad (2.4)$$

$$P_{wg} = \frac{1}{2} \eta_G \rho A_{wt} w_s^3 \quad (2.5)$$

Where

C_p : Turbine efficiency;
 η_{gb} : Efficiency of the speed variator (drive controller);
 η_g : Generator efficiency;
 $A_{wt}[m^2]$: The surface swept by the rotor of the turbine;
 $w_s[m/s]$: Wind speed
 $\rho [kg/m^3]$: the air density.
 $\rho = (353.049/T_a) \cdot \exp(-0.034(Z/T_a))$ (2.6)
 $Z[m]$: Altitude
 T_a The ambient temperature.

C. Modeling of the storage system

The charge-discharge expression of the lead-acid battery is given by the following expression:

$$SOC_{bat} = SOC_{bat}(t-1) + \left(E_{pv}(t) * \eta_{dc} + E_{wt}(t) * \eta_{ac} - \frac{E_{Ld}}{\eta_{inv}} \right) * \eta_{cha} \quad (2.7)$$

With:

η_{inv} : inverter efficiency

η_{cha} : Batteries charging efficiency, generally it depends on charging current. It is between [0.65 and 0.8].

When the load demand is greater than the available energy generated, the battery bank is in discharging state.

Thus, the SOC_{bat} at instant t can be expressed as

$$SOC_{bat} = SOC_{bat}(t-1) + \left(E_{pv}(t) * \eta_{dc} + E_{wt}(t) * \eta_{ac} - \frac{E_{Ld}}{\eta_{inv}} \right) * \frac{1}{\eta_{disch}} \quad (2.8)$$

With η_{disch} batteries discharging efficiency, it supposed equal to 1.

In all cases the state of batteries charging must satisfy the following condition

$$SOC_{bat_min} < SOC_{bat}(t) < SOC_{bat_max}$$

Where

SOC_{bat_min} and SOC_{bat_max} are the limits states of batteries charging.

SOC_{bat_max} is considered like the nominal capacity of the storage system.

$SOC_{bat_max} = C_{bat_n}$

The inferior limit is given by:

$$SOC_{bat_min} = DOD * C_{bat_n} \quad (2.9)$$

DOD(%) the discharging batteries depth. [6]

III. SITE DESCRIPTION

Algeria has high multiple renewable resources.

Adrar is the administrative capital of Adrar Province, the second largest province in Algeria. The commune is sited around an oasis in the Tuat region of the Sahara Desert.

According to a 2008 census it has a population of 64,781, up from 43,903 in 1998, with an annual growth rate of 4.0%. Adrar lies at an elevation of 258 metres (846 ft) above sea level. Geographical coordinates of 27°52'N 0°17'W . Adrar has a hot desert climate (Köppen climate classification *BWh*), with long, hot summers and short, warm winters, and averages just 15 millimetres (0.59 in) of rainfall per year. Summer temperatures are consistently high as they commonly approach 40 °C (106 °F). temperatures at night are still hot at around 27 °C (81 °F). Even in early May or in late September, daytime temperatures can to 45 °C (113 °F). **Figure 2** show Annual map of winds (m/s) in 10m of the ground

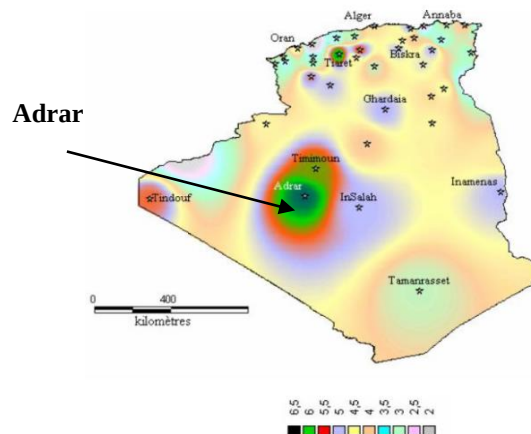


Figure 2 Algeria wind map

A. Wind potential

To evaluate the wind potential of the site, measurements of wind speeds were taken on site with a half hour interval.

Figure 3 shows the profile of the wind in January

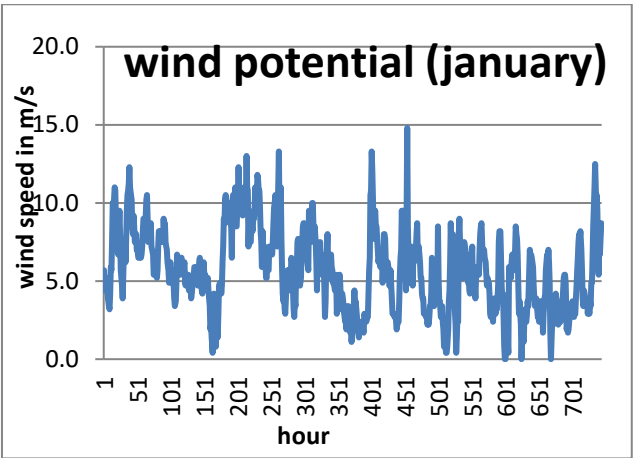
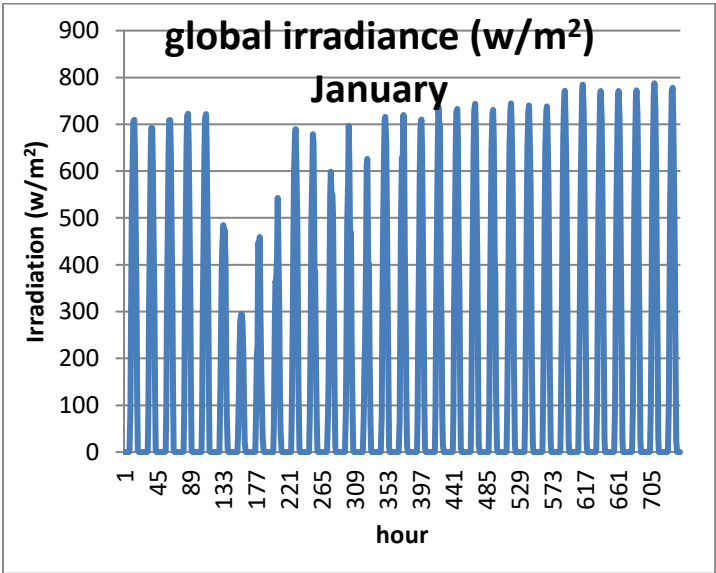


Figure 3 profile of the wind in January

B. Solar potential:

As well as the speeds, measurements of the solar irradiation were taken on the site. By using the orientation and inclination of the PV modules, the latitude of the place and the values of the global radiation.

In (w / m^2), the quantity of the global irradiation received per day for 1 m of horizontal surface is indicated, the mean value of the radiation measured every one hour of January and July is given in **Figure. 4**.



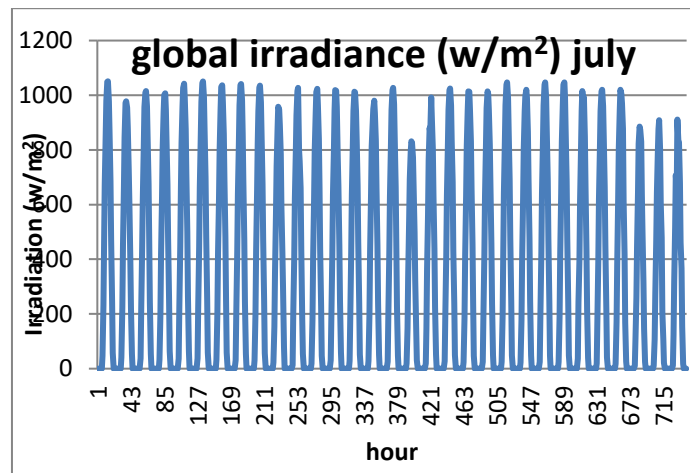


Figure 4 global irradiation in January and july

C. Potential analysis

The annual solar irradiation profile for the proposed site shows that there is a marked seasonal variation in solar irradiation (greater in summer).

The Adrar region has an acceptable wind potential. This feature has led the region to favor initiatives in wind energy generation.

The load profile taken into account in our study is for a typical Adrar village household.

IV. CALCULATION OF THE NUMBER OF CYCLES (NC) ACCORDING TO DEPTH OF DISCHARGE DOD:

The study is based on the mathematical model of a GEL VRLA SOLAR type plate battery given by [10,11]

$$N_{c(DOD)} = 12850e^{-(9.738 \cdot DOD)} + 3210e^{-(1.429 \cdot DOD)} \quad (4.10)$$

To extract the number of cycles (Nc) and the corresponding discharge depth (DOD) the Rain flow algorithm has been applied to the state of charge (SOC) of our system **Figure 5**[12,13,14].

A. Calculation of aging:

The aging rate per cycle ($A_{r/c(DOD)}$) is calculated based on the life cycle of the battery and the DOD.

The expression is written in the following form [10,11]:

$$A_{r/c(DOD)} = \frac{1}{N_{c(DOD)}} \quad (4.11)$$

V. SIMULATION RESULTS

A. Simulation results without isolation

In our case to supply electrical energy to the load of an isolated house we use [1]

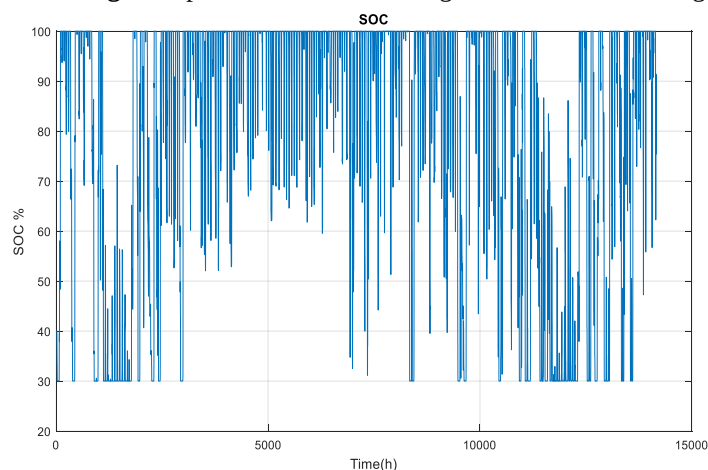
A surface of photovoltaic panels installed: $A_{pv} = 6.03 \text{ m}^2$

A surface swept by the rotor of the wind turbine: $A_{wt} = 6.63 \text{ m}^2$

Storage capacity $C_b = 150 \text{ Ah}$

(The lifetime of 12.38 year and an aging rate 8.08%).

Figure.5 present the state of charge of the batteries during the year



This curve shows the complete exploitation of the batteries in the unfavorable period.

The wind energy produced is equal to 2471.9KW per year, i.e. 8.58W per hour on average, which represents 56% of the energy demanded by the consumer. The photovoltaic energy produced by the Pv panels is equal to 1760.4kW. Comparing to the energy demanded (4386.6kW per year), we find that there is an excess energy at annual level. The latter is explained by the random nature of renewable energy sources.

B. Study of energy efficiency:

TRNSYS software allows the user to construct multi-zone building models and choose the materials for the layers constituting the wall from an existing library. The thermo-physical characteristics of each layer (thickness, density, thermal conductivity, etc.) are defined by the user through the TRNBuild interface[15].

In order to regulate the interior temperature, it is useful to establish the energy balance consumed by air conditioning and heating with / without wall insulation of a house in the Adrar region.

The exterior walls of the house consist essentially of a layer of exterior plaster, brick 10 cm, a strip of area of 10 cm, brick 10cm and a layer of coated plaster and single glazed windows. The thermal insulation of these walls is provided by the addition of a 5 cm layer of expanded polystyrene on the interior faces and the use of double windows.

The following figures show the variation in energy needs for heating and air conditioning before and after insulation, especially as the interior temperature varies according to the temperature of the exterior

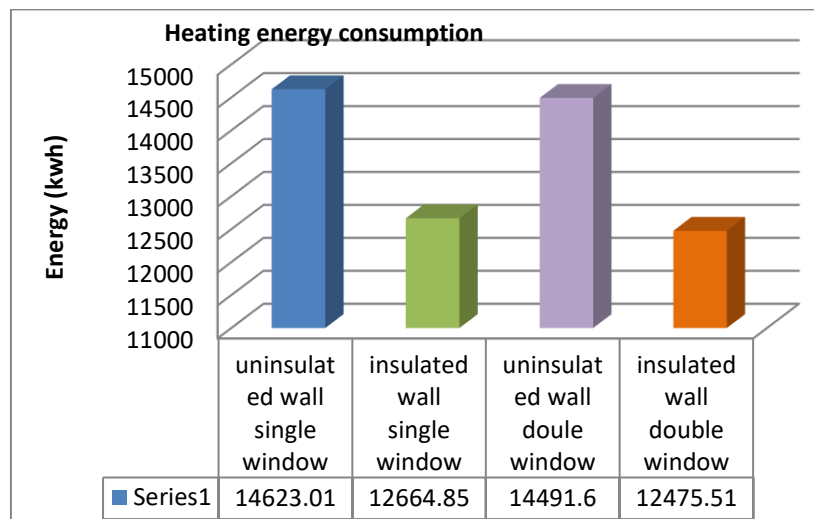


Fig 6 heating energy consumption

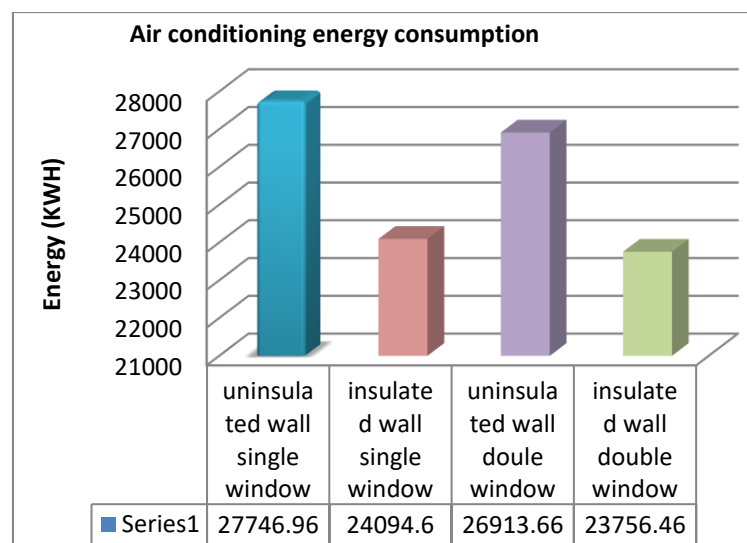


Fig7 air conditioning energy consumption

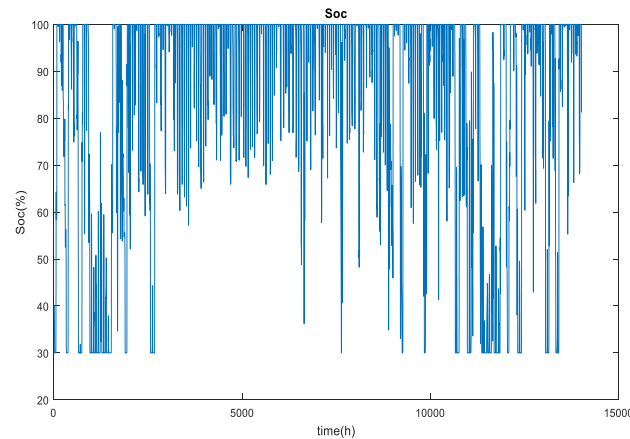
C. Interpretation of results:

The simulation results show that the use of expanded polystyrene for the internal insulation of the walls minimizes energy consumption by 13.39% in the case of heating and 10% in the case of air

conditioning and the use of double glazing saves heating power. 14.68% and 11.73% for air conditioning, therefore an average minimization of energy needs for heating and air conditioning between 11.69% and 13.2% (single / double glazing).

If we assume that a 10% decrease in energy needs for heating and air conditioning by the use of thermal insulation of the walls on this typical house in the Adrar region, we observe its positive effect on the optimization of the lifetime of battery which will increase it to 13.62 years and decrease aging rate to 7.34%.

Fig 8 show the new Soc



VI. CONCLUSION

Given the geographical location, the nature of the terrain and the duration of the sunshine Algeria is one of the model countries in the production of renewable energies.

The work presented in this article concerns the production of electricity from a hybrid system (wind/photovoltaic) with a completely autonomous storage system to supply an isolated village in the Adrar region of southern Algeria.

The objective was to maintain a high level of reliability with a minimum energy loss and low battery aging rate.

In order to maintain the system of renewable energy production and increase its service life, thermal insulation of the walls is necessary; it reduces and saves energy consumption in heating and air conditioning and improves thermal comfort in winter and summer.

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