Hybrid Renewable Energy System Optimization using iHOGA

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Abstract: Electrical energy is considered to be the heart of modern civilization. Traditional electrical energy generation approaches which usually rely on oil and its derivatives, produce different kinds of pollution in addition to being expensive to implement and maintain. And most important, they are exhaustible on the long run. The sun is an unlimited source of energy for humanity around the world and a competitive energy with strong potential. The solar systems technology offers a promising method for the large scale use of solar energy in the southern zone of Algeria. The magnitude of solar radiation is the most important parameter for sizing these systems. This study presents a techno-economic feasibility evaluation for an installation of a stand-alone PV system which covers the electric demand of 20 houses in the province of Tindouf located in the South-West of Algeria. The aim is to select the appropriate components and see the results of the simulation using the hybrid simulator iHOGA, which include the total cost, CO2 emissions and their impact on the environment.

Keywords: HRES, Sizing, Techno-economic Study, iHOGA

1. INTRODUCTION

The traditional power grid, also called the conventional power grid is basically the interconnection of various power systems elements such as synchronous machines, power transformers, transmission lines, transmission substations, distribution lines, distribution substations, and different types of loads. They are located far from the power consumption area and electric power is transmitted through long transmission lines. Traditional power grids have served us for decades because they are predictable and reliable however, Due to the growing concern over climate change caused by greenhouse gases emissions and the brisk increase in electricity demand (2% per year until 2040) which exceeds the demand for any other form of final energy globally, there is a tendency to replace fossil fuels by renewables such as wind and solar [1]**.** The Europe will take the maximum share of 44% of renewable generation in their total energy production [2].

In addition to that Algeria plays an important role as a major exporter of oil and natural gas, It was the fourth largest crude producer in Africa, and the sixth largest natural gas producer in the world, Algeria started an interesting efforts in exploiting renewable energies with the creation of the solar energy institute as soon as 1962, studies of indigenous solar resources performed by the CDER during recent years, show that the climatic conditions in Algeria are favorable for solar energy utilization that can exceed 6 m/s in the South [3–5]. The assessed economic potentials, by the German Space Centre (DLR), of renewable energy sources in Algeria are: Thermal solar: 169 440 TWh/year; Photovoltaic: 13.9 TWh/year.

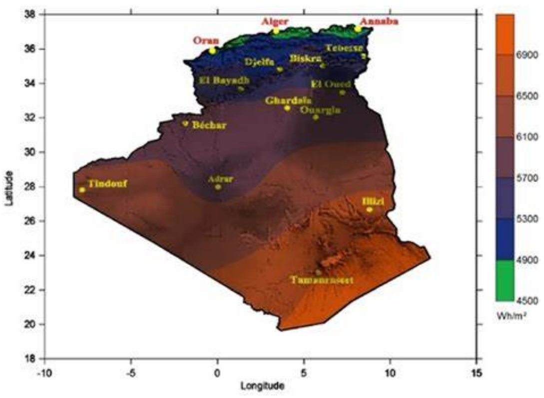


Fig. 1 Annual average irradiation received on a horizontal surface in Algeria for the period 1992-2002

Algeria has a high sun radiation level and is one of the largest markets for solar power in Africa. The country occupies 75% of the Sahara desert territory. The northern part of the country has high solar irradiance rates of 2650 KWh per m2. In 2016, the country's total solar installed capacity was more than 240 MW. Under the National Development

Plan for Renewable Energies, the country aims to install renewable generation capacity of 22 GW by 2030, with solar accounting for almost 60% of the capacity [6]. As a result, the demand for solar energy is expected to grow in the country during the forecast period.

Table 1 Algeria sun capacity

Region	Coastal regions	highlands	Sahara
Area	4	10	86
Average duration of sun exposure $(h/year)$	2650	3000	3500
Average energy received $(Kwh/m^2/year)$	1700	1900	2650

The main objectives to achieve in optimizing a hybrid renewable energy system by applying any suitable technique is to identify the system component values, set up the objective function containing the variables and components along with the realistic constraints which can affect the function so that the load demand can be economically and effectively satisfied. Hence, the objective function of the optimization problem with its overall system components are found subject to Minimizing the total net present cost invested in the system and Ensuring that the load is served according to some reliability criteria.

A look at the literature suggests that the use of optimization techniques to solve the problem of sizing renewable energy systems can be categorized into different approaches. One approach is using a graphical representation. This approach generally works well for problems with two design variables by observing graphically how they change one with respect to the other. The constraints are plotted in the same graph. By inspection of the feasible region, the optimized point on the graph can be identified once the objective function contours are drawn [7, 8]. Another way is the probabilistic approach in which the optimum size of hybrid PV/wind energy system is calculated on an hourly basis or daily average power per month, the day of minimum PV power per month, and the day of minimum wind power per month. Two advantages of this method are that the cost and time of environmental and load data collection are minimum [9, 10]. The other approach is named deterministic approach where, every set of variable states is uniquely determined by parameters in the model and by sets of previous states of these variables, thus there is always unique solution for given parameters, unlike probabilistic approach [11].

The classical iterative approach is a mathematical procedure generally performed using computer that generated a sequence of improving approximate solution for the optimization problem until a termination criteria is reached. As the number of optimization variables rises, the computation time increases exponentially when using this approach [12-13]. Artificial intelligence (AI) consisting of tools such as artificial neural networks (ANN), genetic algorithms (GA), fuzzy logic (FL) and hybrid systems has been used as a tool to optimize HRES. The use of intelligent technologies results in practicable systems with better performance that classical methods are not able to achieve [14]. Examples include: Genetic Algorithms [15], Particle Swarm Optimization [16] and Artificial Neural Networks [17]. Some dedicated software packages have been also proposed including HOMER (Hybrid optimization method for electric renewable) [18], iHOGA (Hybrid optimization by genetic algorithm) and HYBRD2 [19].

Throughout this work, a techno-economic feasibility evaluation of fixed panels, off-grid solar PV system using batteries and a backup generator mounted in Tindouf province situated in the South West of Algeria is presented, analyzed and simulated using iHoga software. The Results led to appropriate sizing of components and technical indicators describing the productivity and performance of the installation project.

2. iHOGA SOFTWARE

iHOGA (Improved Hybrid Optimization by Genetic Algorithms) is a software developed in C++ by researchers of the University of Zaragoza (Spain) for the simulation and optimization of Electric Power Generation Systems based on Renewable Energies , off-grid (stand-alone systems) or grid-connected systems. The software can model systems with electrical energy consumption load (DC and/or AC) and/or Hydrogen, as well as consumption of water from tank or reservoir previously pumped. It can include different components: photovoltaic generator (included bi-facial and CPV), wind turbines, hydroelectric turbine (with or without pumped hydro storage), auxiliary generator (diesel,

gasoline …), inverter or inverter-charger, batteries (lead-acid or li-ion), charger and batteries charge controller as well as components of hydrogen (electrolyzer, hydrogen tank and fuel cell). The program can simulate and optimize off-grid systems of any size up to 5 MW.
Two different kinds of projects can be simulated and optimized: low power or high power systems. The low power systems include off-grid or grid-connected systems, where the load is not too high and we want to cover the electrical demand at the minimum cost. The system can be DC or AC coupled. Power is measured in W, monthly or annual energy in kWh and costs in the monetary unit (Euro, Dollar or any other currency). The high power systems include grid-connected systems, where a high load must be covered (big farm or a village), where we want to cover the demand at the minimum cost, or generator systems (without any load) where we want to maximize the benefits of selling electricity to the grid. The system is AC coupled. Power is measured in kW, monthly or annual energy in MWh and costs in kilo monetary units (k€, k$ or any other).
The software allows for multi-objective optimization depending on the type of the system. For the high power system, all or almost all the electricity is sold to the AC grid and optimization is achieved by maximizing the total incomes during the system lifetime (Net Present Value, NPV). For the low power system, there is the financial optimization in which the load demand is satisfied along with minimizing the total system costs throughout the whole lifespan of the system. These costs are referred to or updated for the initial investment (Net Present Cost, NPC).
Additional variables may also be minimized like the total equivalent CO2 emissions generated by the AC generator fuel (diesel or gasoline) as well as those generated in the manufacturing and transportation. Unmet load (energy not served), the Human Development Index (HDI) and job creation, optimizing temporary installations over a period of time by minimizing the associated cost (transport + operation and maintenance + degradation) or the weight to be transported are all performance criteria that can be considered for optimization.
The program can also optimize the combination of elements and also the control strategy which determines when batteries or diesel generation sets must supply the load, to what level the batteries should be charged.

The program includes multi-period simulation and optimization (considering the increase in load and the decrease of electricity production from the renewable sources during the years of the system lifetime), multi-objective optimization, simulation in time steps from 1 minute to 1 hour, sensitivity analysis, probability analysis (Monte Carlo simulation), etc.

3. SYSTEM SPECIFICATIONS

The system under consideration in this study is shown is Fig. 2. It is a standalone system consisting of PV array, converters, Backup Diesel generator and a load. The loading of the system is for an isolated area having 20 houses. All the specifications of the system are based on real life data to make the project as realistic as possible.

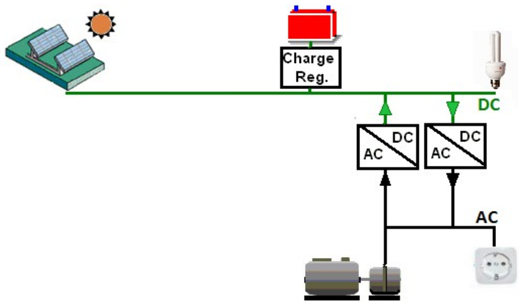


Fig. 2 The considered standalone photovoltaic system

Location

The off-grid PV system study was established on the rooftop of 20 houses in Tindouf, Algeria, the GPS coordinates are as follows 27°36'56 N 8°11'09W. .

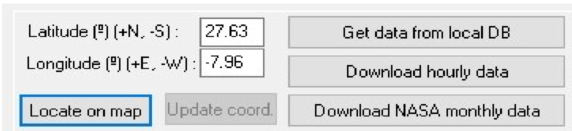


Fig. 3 Latitude and longitude of Tindouf

The corresponding coordinates are located on the map to get the climate characteristics of this region.

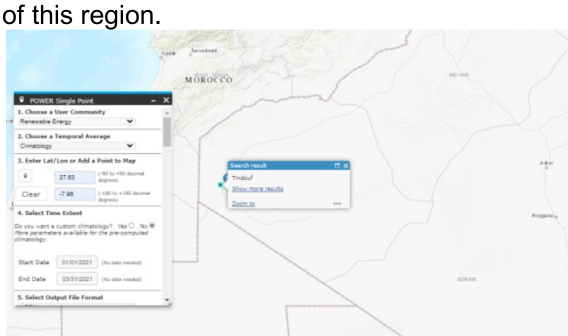


Fig. 4 The latitude and longitude of Tindouf provided by NASA

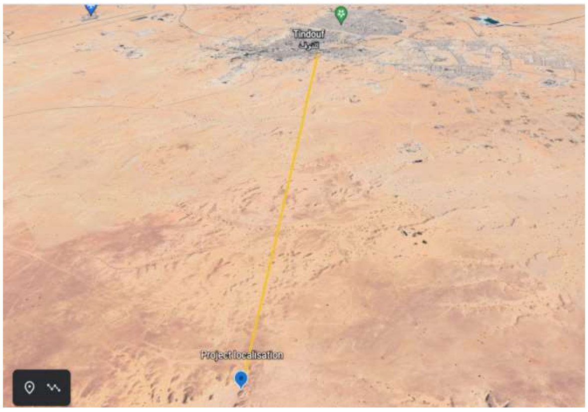


Fig. 5 localization of the project on Google earth

Climate Information

System orientation

- **a- Solar Panel Orientation:** refers to our *azimuth* setting. Most of the energy coming from the sun arrives in straight line. A solar panel or solar array will capture more energy if it is facing directly at the sun, perpendicular to the straight line between the position of the panel's installation and the sun. Then, we need to have the solar panel turned towards the terrestrial equator (either facing south in the northern hemisphere, or north in the southern hemisphere) so that during the day its orientation allows the panel to catch the greatest possible amount of solar radiation possible.

- **b- Tilt angle (β)** is the angle between the panels and the horizontal plane. This angle is south oriented in the Northern Hemisphere and north oriented in the Southern Hemisphere. Tilt angle varies between 0º and 180º. When a plane is rotated about horizontal east-west axis with a single daily adjustment. The tilt angle of the surface will be fixed for each day and is calculated by the following equation:

$$\beta = \varnothing - \delta \tag{1}$$

Where,

The latitude angle (Ø): is the angle forming according to the equator center.

The inclination angle (δ): is the angle between the sun lights and the equator plane.

According to NASA satellite data of the Tindouf's site location, the tilt angle of each month during a year is shown in Table 2.

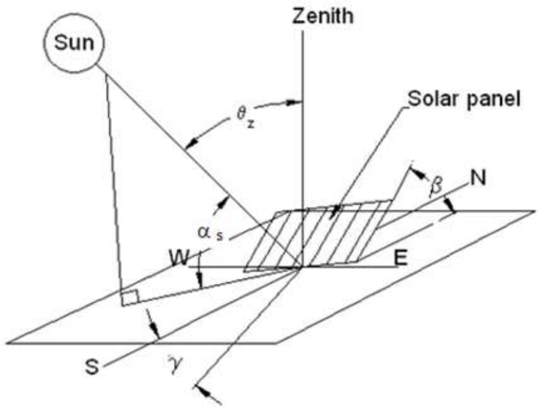


Fig. 6 Tilt angle of system orientation

Table 2 Best tilt angle for each month in Tndouf

Jan	Feb	Mar	Apr	May	Jun
54.50°	45.50°	31.00°	15.00°	0.50°	0.00°
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0.00°	9.00°	23.00°	39.00°	50.50°	56.00°

The yearly optimum tilt angle is defined as 56° in December since it has the lowest radiation (unfavorable sunshine) with 6.88kWh/m2.

We enter the specified data in the simulator:

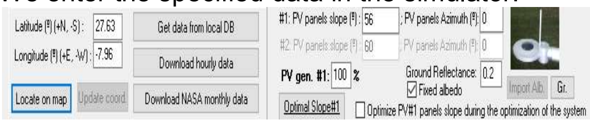


Fig. 7 Localization and panel's characteristics

- **c- Radiation on the horizontal and tilt surface:**

Solar radiation data is the key point for the planning and sizing of the PV system. They are extracted through the calculation of the amount of solar radiation for each square meter per month in the selected area. The average monthly resources data are automatically downloaded in IHOGA from NASA POWER (https://power.larc.nasa.gov/) for a specific year (2019) for both horizontal and tilt surfaces. Figure((()))) shows the resulted solar irradiations.

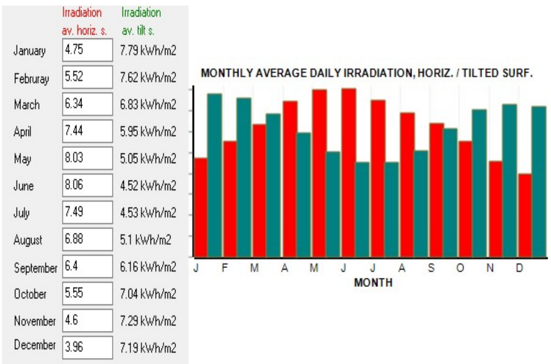


Fig. 8 The dowloaded average irradiation (kWh/m²) for both horizontal and tilt surfaces

According to NASA satellite, the total annual irradiations on both surfaces are represented in fig. 9.

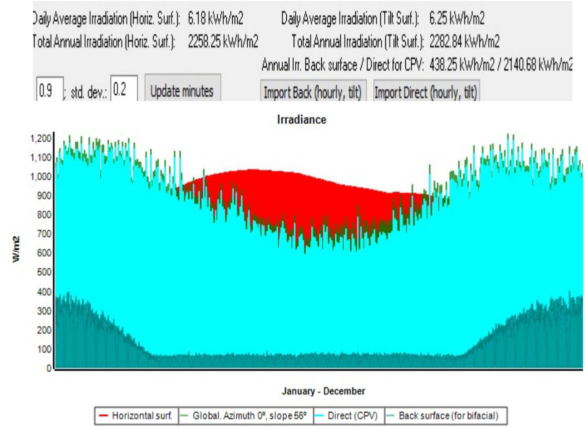


Fig. 9 Total irradiance during one year in W/m^2

The estimated Electric Load

The objective of this work is to design a PV system which can produce sufficient electrical energy to 20 houses. Therefore, we have to estimate the energy demand of the load by calculating the daily average power consumption of each appliance taking into consideration the winter and summer uses. The results of consumption of for **one house** are shown in table 3.

There are 3 options to introduce data sources on load:

- Load profile: For loads corresponding to profiles predetermined by the system or created by the user, the default profile is charged
- Import hourly data file : We can import hourly (or in several minutes steps) consumption data for a whole year
- Monthly average: This is adequate in case the expected load is known in monthly average hourly values. Data on load must be introduced on the load tables in watts for AC and DC.

Load profiles are shown for each month**;** we take the example of 2 months August (summer period) and December (winter period) to see the difference in the electricity consumption.

Variability: we set the percentage of variability or randomness of AC load both daily and for each hour, and for each minute. The program will calculate the consumption for each hour taking this into account. Once the hourly and minute load has been **generated**, we can add a AC, DC consumption by specifying the day, duration and whether it is repeated during the whole year.

Table 3 The considered load consumption in kW

Electrical loads	Number of devices	Consumption kW (for one hour)	Number of hours per day	Days per month	Winter consumption KWh/day (Nov-Feb)	Summer consumption KWh/day (march - Oct)
(combi fridge) of 250L	1	0.150	24	30	3.6	3.6
TV LCD	2	0.150	4	30	0.9	0.9
Washing machine of 7kg with hot watter	1	2	3	12 = 3× 4	6	6
Iron	1	1	1	10	1	1
Lamps LED	10	0.008	6	30	0.48	0.48
flat screen Computer	2	0.1	3	12 = 4× 3	0.9	0.9
Phone charger (DC)	4	0.007	2	30	0.056	0.056
Air conditioner (18000 BTU)	1	5.278	12	30	/	63.336
Wifi router (TP-Link)	1	0.009	24	30	0.216	0.216
Water heater	1	1	2	25	2	2
Hair straightner	1	0.016	2	8	0.032	0.032
Vaccum cleaner	1	1.4	1	8	1.4	0.12
Electric stove	1	2	2	30	4	4
Cooling fan	2	0.05	24	30	/	1.2

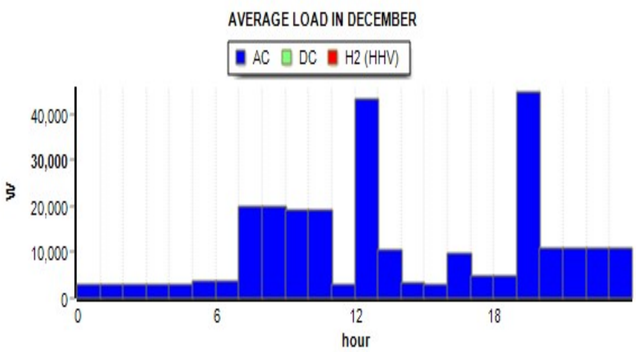


Fig. 10 Average load consumption in December

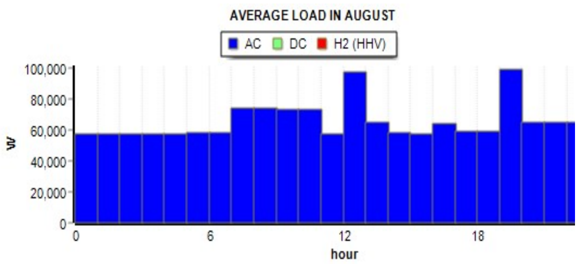


Fig. 11 Average load consumption in August

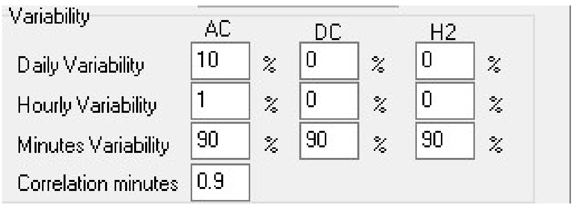
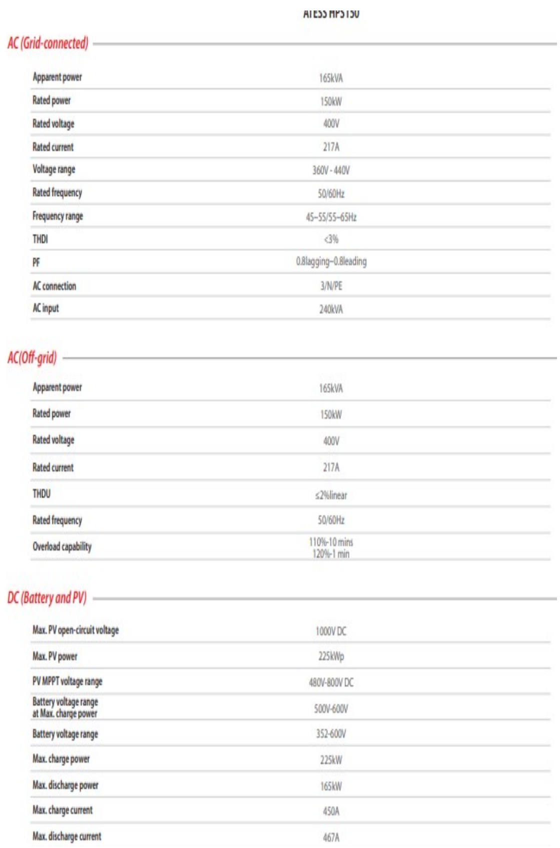


Fig. 12 Percentage of variability (daily, hourly, minutes)

4. *RESULTS AND DISCUSSIONS*

Sizing and Specifying an Inverter

The selection of the inverter depends on the peak load consumption in watts in one day, since the peak is 124591 W so we select the inverter **ATESS HPS150**which can be used in both off-grid and grid-connected systems and has the parameters in Fig. 13.



	ATESS HPS150
AC (Grid-connected)	
Apparent power	165kVA
Rated power	150kW
Rated voltage	400V
Rated current	217A
Voltage range	360V - 440V
Rated frequency	50/60Hz
Frequency range	45~55/55~65Hz
THDI	<3%
PF	0.8lagging~0.8leading
AC connection	3/N/PE
AC input	240kVA
AC(Off-grid)	
Apparent power	165kVA
Rated power	150kW
Rated voltage	400V
Rated current	217A
THDU	≤2%linear
Rated frequency	50/60Hz
Overload capability	110%-10 mins 120%-1 min
DC (Battery and PV)	
Max. PV open-circuit voltage	1000V DC
Max. PV power	225kWp
PV MPPT voltage range	480V-800V DC
Battery voltage range at Max. charge power	500V-600V
Battery voltage range	352-600V
Max. charge power	225kW
Max. discharge power	165kW
Max. charge current	450A
Max. discharge current	467A

Fig. 13 Atess HPS150 datasheet

This type of inverter includes battery charger of type MPPT inside it. The inverter general data entered in the simulator are described in the table 4.

Table 4 The inverter general data

Power(W)	150000
Lifespan (year)	10
Aquisition cost (€)	22491 (18900 + 19% of the tax)
Battery charger	OK (included)
Efficiency (%)	99.9
Maximum charge current of battery	450
Maximum input power from the photovoltaic generator	225000
Vdcmin/Vdcmax	480/800

Sizing and Specifying batteries

Our system supply a high load so we selected the **battery bank 48V 500ah lifepo4 (lithium)** of **Cmax batteries** which is a combination of 5pcs CMX48100. 5pcs modular connect in parallel total 48v 500Ahand 25Kwh storage system. The System nominal voltage is 51.2v with 16S LiFePo4 cells. The main characteristics of this type of battery are:

- The ups battery 48v 500ah is maintenance free. module is design for easy installation and capacity expansion.
- This battery module with High Capacity Long cycle life. 20 years solar storage battery design supplier
- Lithium ion battery packs wide working temperature range and high reliability.
- Multiple battery module units can be connected in parallel, suitable for high energy storage applications.
- Compatible with various charge controllers and inverters.
- Widely used for off-grid solar system storage, telecom lithium batteries, ups battery…etc.

The details specifications provided by the manufacturer are described in table 5.

Table 5 Manufacturer's specifications for the battery bank

Battery type	LiFePO4 battery
Rated voltage (V)	51.2V
Nominal capacity (Cn) in Ah	500
Nominal voltage (V)	48
Acquisition Cost (€)	4760 (4000€ +19% of tax)
Max. Discharge Current(A)	100
Cycle Life	>6000cycles
Weight (kg)	280
Self discharge Coefficient (monthly %)	<3%
Working temperature	-20°C~60°C

The cycle life and capacity depend on temperature by selecting the checkbox

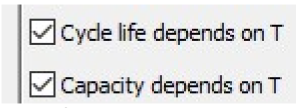


Fig. 14 Cycle life and capacity dependence on temperature

The annual inflation rate expected for batteries costs is -2%

The calculation of the estimated lifespan of the batteries is very important, since it influences the replacement costs of these and therefore in the total cost of the system. There exist 5 models (methods) in Lithium batteries to estimate the lifetime including the SOC, Imax…., which are : The Equivalent Full Cycle life model, Cycle Counting or (Rainflow) method, Wang, Grot and Saxena methods obtained by testing specific commercial batteries.

Photovoltaic modules

The photovoltaic modules screen may be accessed by selecting "PV modules" in the Data menu. The selected module in our project is **JAM72S30-550/MR** solar panel from **JA Solar Technology.**

The parameters of the **JAM72S30-550/MR** solar panel are given in Fig. 15 with the specifications given in Fig. 16.

ELECTRICAL PARAMETERS AT STC

TYPE	JAM72S30 -525/MR	JAM72S30 -530/MR	JAM72S30 -535/MR	JAM72S30 -540/MR	JAM72S30 -545/MR	JAM72S30 -550/MR
Rated Maximum Power(Pmax) [W]	525	530	535	540	545	550
Open Circuit Voltage(Voc) [V]	49.15	49.30	49.45	49.60	49.75	49.90
Maximum Power Voltage(Vmp) [V]	41.15	41.31	41.47	41.64	41.80	41.96
Short Circuit Current(Isc) [A]	13.65	13.72	13.79	13.86	13.93	14.00
Maximum Power Current(Imp) [A]	12.76	12.83	12.90	12.97	13.04	13.11
Module Efficiency [%]	20.3	20.5	20.7	20.9	21.1	21.3
Power Tolerance	0~+5W					
Temperature Coefficient of Isc(α_Isc)	+0.045%/℃					
Temperature Coefficient of Voc(β_Voc)	-0.275%/℃					
Temperature Coefficient of Pmax(γ_Pmp)	-0.350%/℃					
STC	Irradiance 1000W/m², cell temperature 25℃, AM1.5G					

Remark: Electrical data in this catalog do not refer to a single module and they are not part of the offer.They only serve for comparison among different module types.

ELECTRICAL PARAMETERS AT NOCT

TYPE	JAM72S30 -525/MR	JAM72S30 -530/MR	JAM72S30 -535/MR	JAM72S30 -540/MR	JAM72S30 -545/MR	JAM72S30 -550/MR
Rated Max Power(Pmax) [W]	397	401	405	408	412	416
Open Circuit Voltage(Voc) [V]	46.05	46.18	46.31	46.43	46.55	46.68
Max Power Voltage(Vmp) [V]	38.36	38.57	38.78	38.99	39.20	39.43
Short Circuit Current(Isc) [A]	10.97	11.01	11.05	11.09	11.13	11.17
Max Power Current(Imp) [A]	10.35	10.39	10.43	10.47	10.51	10.55
NOCT	Irradiance 800W/m², ambient temperature 20℃,wind speed 1m/s, AM1.5G					

OPERATING CONDITIONS

Maximum System Voltage	1000V/1500V DC
Operating Temperature	-40℃~+85℃
Maximum Series Fuse Rating	25A
Maximum Static Load,Front* Maximum Static Load,Back*	5400Pa(112lb/ft²) 2400Pa(50lb/ft²)
NOCT	45±2℃
Safety Class	Class Ⅱ
Fire Performance	UL Type 1

Fig. 15 Parameters of the **JAM72S30-550/MR** solar panel

SPECIFICATIONS

Cell	Mono
Weight	28.6kg±3%
Dimensions	2279±2mm×1134±2mm×35±1mm
Cable Cross Section Size	4mm² (IEC) , 12 AWG(UL)
No. of cells	144(6×24)
Junction Box	IP68, 3 diodes
Connector	QC 4.10(1000V) QC 4.10-35(1500V)
Cable Length (Including Connector)	Portrait: 300mm(+)/400mm(-); Landscape: 1300mm(+)/1300mm(-)
Packaging Configuration	31pcs/Pallet, 620pcs/40ft Container

Fig. 16 Specifications of the **JAM72S30-550/MR** solar panel

The panel considered in the optimization is parameterized in a line of the table in iHOGA as:

Nominal voltage: The nominal voltage is obtained as a function of the open circuit voltage: since the open circuit voltage is between 40 and 60 V so $V_{nominal}$ is 24V

C.O&M (€/year): The unit cost of operation and maintenance (O&M) is the cost per panel of the photovoltaic generator, apart from the **fixed O&M cost** for the whole set of modules of the generator is 10% of the panel cost so equals to 2.1 €/year

Pn (Wp): Peak nominal power under standard test conditions (STC) equals to 550W.

STC: Standard test conditions are the laboratory conditions under which all PV modules are tested which are :

- An irradiance of 1000 watts per square meter, which simulates peak sunshine on a surface directly facing the sun in a day without clouds.
- Temperature of the cell – 25°C. The temperature of the solar cell itself, not the temperature of the surrounding.
- Mass of the air – 1.5. This number is somewhat misleading as it refers to the amount of light that has to pass through Earth's atmosphere before it can hit Earth's surface, and has to do mostly with the angle of the sun relative to a reference point on the earth. This number is minimized when the sun is directly above as the light has to travel a minimum distance straight down, and increases as the sun goes farther from the reference point and has to go at an angle to hit the same spot.

NOCT: stands for the Nominal Operating Cell

Temperature, it provides a more realistic idea of how solar panels will perform in actual practice.
NOCT is reached when the following conditions are met:

- The irradiance is 800 watts per square meter, which takes into account the fact that PV modules don't always face the sun. It also considers atmospheric or geographic conditions what might diminish sunshine.
- Solar panels heat up considerably during operation, so the temperature considered is 45 (+/- 3) °C.
- The light spectrum is the same as for STC.
- A wind speed of 1 m/s is considered, with air at 20°C

NOCT of our panel is equal to 45°C
Temperature coefficient of Pmax Ct (%/ºC) : It is only necessary if one wants to consider the effect of temperature in the power, taken -0.350 (%/ºC) from the panel datasheet.

Results

For a multi-period simulation (simulation of the system lifetime of 25 years), we will see the results for a multi-objective optimization which includes Minimization of Total Cost (NPC), CO2 emissions and unmet load using two different control strategies: load following and cycle charging.

a- Using load following method

For Radiation = 6.25kWh/m^2, interest I= 4%, inflation g=2%, the simulator has performed 1978 iterations, where it took all cases from the lowest NPC to the highest one, the first 8 iterations are shown in the table:

Table 6 Results of the first 8 iterations (Load following)

(NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W)	Ren(%)	LCOE(€/kWh)
867390.4	162154	0	0	INF	6.4	83.9	0.09
887168.5	161874.47	0	0	INF	7.3	84	0.09
902193.6	162158.62	0	0	INF	8.2	84	0.1
922514.4	162470.03	0	0	INF	9.2	84	0.1
942703.6	162818.36	0	0	INF	10.1	84.1	0.1
963434.1	163161.23	0	0	INF	11	84.1	0.1
979473	163523.34	0	0	INF	11.9	84.1	0.1
999463.9	163829.12	0	0	INF	12.8	84.2	0.11

The results of the first iteration which provides better solutions are shown in the next tables:

Table 7 Resulting system

Component	specifications
PV generator JAM72S30-540/MR	24 × 39 × 540Wp
Max number of batteries	12 × 7 × 500Ah
I AC diesel generator Caterpillar	250KW
Inverter ATESS-HPS 150	150KW

Table 8 System Cost breakdown

Cost type	Price (€)
Initial investment	427846.1
annual quota	**48732.5**
Average year Cost of AC generator fuel	**3996.9**
Total System Costs (NPC)	**867390.4**
Levelized cost of energy	0.09/kWh
PV Generator Costs (NPC)	**250803.6**
Battery bank Costs (NPC)	**148160**
ACGenerator Costs (NPC)	**274411.1**
Inverter Costs (NPC)	**49344**
AC Generator Fuel Costs (NPC)	**78393**
Installation+ financing (NPC):	**66278.2**

Other results: the report attached to the simulation results provide us with the following information:
a) Battery Lifetime: 17.28 years
b) Equivalent Hours of AC Generator operation: 1294.92h/yr
c) Total CO_2 emissions: 162154 kgCO2/yr, where emissions of AC generator (due to consumption of 39741.484 liter/yr): 139095.2 kg CO2/yr.
d) Human Development Index (HDI): 1.0896.
e) Jobs created during system lifetime: 1.5552.

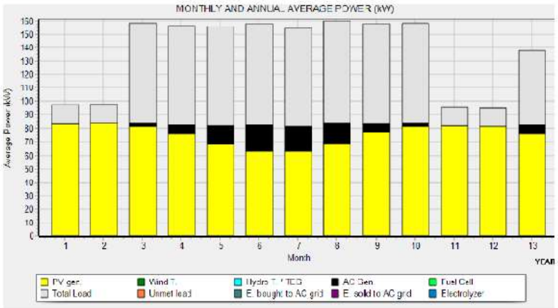


Fig. 17 Monthly and annual average power

b- Using cycle charging method

For Radiation= 6.25KWh/m^2, interest rate I= 4%, inflation rate g=2%, the simulator performed 1978 iterations, where all cases having the lowest NPC to the highest one. The first 8 iterations are shown in table 9:

Table 9 Results of the first 8 iterations (Cycle Charging)

Total Cost (NPC)(€)	Emission (kgCO2/yr)	Unmet(kWh/yr)	Unmet(%)	D.aut	Cn(Wh)/(Ppv+Pw)(W)	Ren(%)	LCOE(€/kWh)	Simulate
872697.2	188151.03	0	0	INF	15	69.9	0.09	SIMULATE
890547.9	187428.12	0	0	INF	16.1	70.2	0.1	SIMULATE
906078	187096.56	0	0	INF	17.3	70.4	0.1	SIMULATE
926001.5	187078.14	0	0	INF	18.4	70.5	0.1	SIMULATE
946278.3	187219.23	0	0	INF	19.6	70.6	0.1	SIMULATE
966899.2	187581.17	0	0	INF	20.7	70.6	0.1	SIMULATE
987404.2	187870.95	0	0	INF	21.9	70.7	0.11	SIMULATE
1008068.7	188286.8	0	0	INF	23	70.7	0.11	SIMULATE

The type of components to be used in this system and their numbers are given in table 10 with the different costs in our system summarized in table 11.

Table 10 system component specifications (Cycle Charging)

Component	Specifications
PV generator JAM72S30-550/MR	24 x 39 x 540Wp
Max number of batteries	12 x 7 x 500Ah
1 AC diesel generator Caterpillar	250KW
Inverter ATESS-HPS 150	150KW

Table 11 System Cost breakdown (Cycle Charging)

Cost type	Price (€)
Initial investment	**478960.3**
annual quota	54554.5
Average year Cost of AC generator fuel	**4862.3**
Total System Costs (NPC)	872697.2
Levelized Cost of energy	0.09/kWh
PV Generator Costs (NPC)	202575.4
Battery bank Costs (NPC)	**259087.6**
ACGenerator Costs (NPC)	192710.5
Inverter Costs (NPC)	49344.5
AC Generator Fuel Costs (NPC)	**95368.4**
Installation+financing (NPC):	**73610.8**

Other results:

– Batteries Lifetime: 19.48 years

– Equivalent Hours of AC Generator operation: 876.17 h/yr

– TotalCO2 emissions is 188151.03 kgCO2/yr where, emissions of AC generator (due to consumption of 47048.516 liter/yr) are 164669.81 kgCO2/yr

– Human Development Index (HDI): 1.0896.

– Jobs created during system lifetime: 1.2477

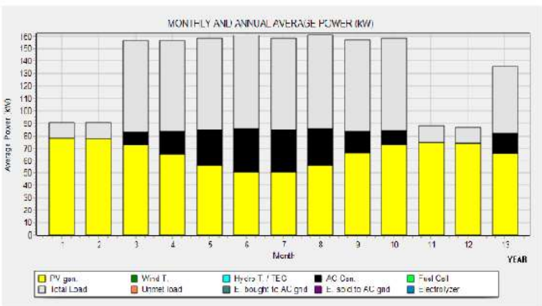


Fig. 18 Monthly and annual average power

Comparing the two strategies **«load following»** and **«cycle charging»**, we see that there is no great difference in terms of **total costs results (NPC)**. However, for **CO2 emissions,** the cycle charging method has more impact on the environment due to its highest level of gas emissions because of the backup generator's rated power. In both methods, the load demand is well satisfied by the system components taking into account variability which may occur.

5. CONCLUSIONS

Throughout this work, the techno-economic feasibility evaluation of fixed panels, off-grid solar PV system using batteries and a backup generator installed in Tindouf province has been presented, analyzed and simulated using iHOGA software. The results produce the appropriate sizing of various system components and the technical indicators describing the productivity and performance of the project. Algeria is particularly exposed to climate change. Therefore, a set of actions related to the energy, forests, industry, and waste sector have been programmed along the period 2015 to 2030, with the government action program giving priority to promote renewable energies. The study in this work proved that the proposed system is reliable, cost-effective and also environmentally friendly since it will be able to reduce CO_2 emissions into the atmosphere.

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