Optimization of a Hybrid Wind-Pv-Diesel Standalone System: Case Chlef, Algeria

T. Tahri, A. Bettahar, and M. Douani

Abstract—In this work, an attempt is made to design an optimal wind/pv/diesel hybrid power system for a village of Ain Merane, Chlef, Algeria, where the wind speed and solar radiation measurements were made. The aim of this paper is the optimization of a hybrid wind/solar/diesel system applied in term of technical and economic feasibility by simulation using HOMER. A comparison was made between the performance of wind/pv/diesel system and the classic connecting system.

Keywords—Chlef-Algeria, Homer, Renewable energy, Wind-pv-diesel hybrid system.

I. INTRODUCTION

STAND-alone renewable energy systems constitute an alternative to the grid connected systems. They include solar radiation, wind and hydraulic sources which are essentially inexhaustible resources. The amount and proportion of renewable energy generated is expected to rise so largely because of the ever diminishing supplies of gas and oil and also because of the international awareness and programs to support renewable energy generation [1]. A power generating system which combines two or more different sources of energy is called a hybrid system. The hybrid energy generating systems (such as wind-diesel, pv-diesel, wind-pv-diesel etc. with and without battery storage options) are not new technologies or systems rather existed in practice for the last two decades as mentioned by Yang et al. [2].Hybrid systems such as wind-diesel or photovoltaic-diesel are now proven technologies for electric supply in remote locations [3]. The authors have recommended an optimal design model for hybrid solar-wind system which employed battery banks to calculate the system's optimum configurations in China. In another study, Yang et al. [4] recommended an optimal sizing method to optimize the configurations of a hybrid solar-wind system with battery banks. The authors used a genetic algorithm (GA) to calculate the optimum system configuration that could achieve the customers required loss of power supply probability (LPSP) with minimum annualized cost of system (ACS). However, before any implementation of renewable energy system, a technical and economic feasibility study is necessary to justify the investments and the budgets allocated to their

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implementation. The design of hybrid renewable energy systems requires appropriate dimensioning in terms of power as well as suitable choice of the system components according to the available resources. For this reason, simulation software packages constitute an essential tool for the analysis and the comparison of different combinations and alternatives. Analysis must take into consideration three main constraints: First, the available renewable resources in a given region. Second, the load profile and last the availability of financial resources [5]. Recently, Dihrab and Sopian [6] proposed a hybrid power system to generate power for grid connected applications in three cities in Iraq. Results showed that it is possible for Iraq to use the solar and wind energy to generate enough power for villages in the desert and rural areas. Nfah et al. [7] studied a solar/diesel/battery hybrid power system to meet the energy requirements of a typical rural household in the range 70-300 kWh/yr and found that a hybrid power system was comprising a 1440 Wp solar pv array and a 5 kW single-phase generator operating at a load factor of 70%, could meet the required load. Saheb-Koussa [3] designed a wind/pv/diesel hybrid energy system with battery backup and conducted its techno-economical feasibility for remote applications in Algeria. Their simulation results indicated that the hybrid system is the best option for all the sites considered, provided higher system performance than photovoltaic or wind alone systems, the reliability of the system enhanced, and finally it was revealed that the energy cost depends largely on the renewable energy potential. Ekren et al. [8] designed and developed an optimum sizing procedure of windepvediesel hybrid system for small applications in Turkey. HOMER software is a user-friendly micropower design tool that simulates and optimizes stand-alone and grid-connected power systems. Recently, it is has been used widely in the field of renewable energy [9]. It can be used with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, microturbines, batteries, and hydrogen storage, serving both electric and thermal loads. The advantage of the HOMER is that it can involve also all costs such as the initial capital and the maintenance costs including pollution penalties. The simulation considers a one-year time-period using a minimum time-step of 1 min. It performs a sensitivity analysis which can help the analyst to do 'what-if' analyses and to investigate the effects of uncertainty or changes in input variables. The objective of the optimization simulation is to evaluate the economic and technical feasibility for a large number of technology options, while considering variations in technology costs and energy resource availability [10].

In this work, an attempt is made to design an optimal wind/pv/diesel hybrid power system for a village of Ain Merane, Chlef, Algeria, where the wind speed and solar radiation measurements were made. The aim of this paper is the optimization of a hybrid wind/solar/diesel system applied in term of technical and economic feasibility by simulation using HOMER. A comparison was made between the performance of wind/pv/diesel system and the classic connecting system in Ain Merane.

II. Site and Data Description

The meteorological data (wind speeds, global solar radiation) were measured at Ain Merane village the entire year 2011. The global solar radiation data was measured using a pyranometer. The geographical coordinates of the data collection site were 36° 42' N latitude, 1° 25' E longitude and 143 m altitude above mean sea level.

A. Solar Data

The primary source of daylight is the sun. From measurements over a long period, it has been concluded that the mean values of luminance from the sun and from the sky on a plane are related to the geometrical position of the sun in the sky and to the conditions of the sky.
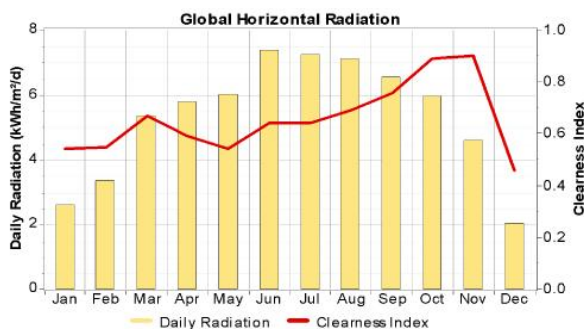

Fig. 1 Monthly mean daily global horizontal solar radiation at Chlef

Based on measured daylight data, several mathematical models of sunlight and skylight have been developed for various locations. The values calculated by the models are used to present average values for the given sky condition. The horizontal solar radiation data estimated for the site of Ain Merane, Chlef region is shown in Fig. 1. The distributions show an almost similar behavior with a minimum of 2 kWh/m^2/d daily solar radiation. From April to October, this radiation is greater than 6 kWh/m^2/d. This can be amounted to the fact that Chlef is in the North of Algeria with very frequent changes in weather in winter. However, for the months of July and June; various regions in Algeria show similar levels of radiation and hence constitute a considerable potential for solar energy generation.

B. Wind Data

The data presented graphically in Fig. 2 are monthly averages of wind speed measured at the site. The values of wind speed are measured every hour of day during year 2011.

It can be noticed that both sites are characterized by an important wind potential with an annual average speed of v=5.367m/ s.
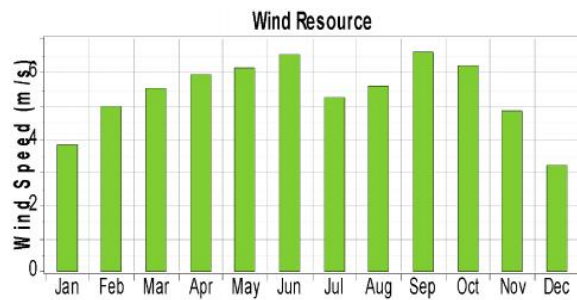

Fig. 2 Monthly mean wind speed at Chlef

We can noted that the difference between the monthly averages of wind speed are important; the windiest months are certainly those of May (v=6.13 m/s), June (v=6.51 m/s), September (v=6.58 m/s) and October (v=6.20 m/s). However, for the months of December and January, the wind speed does not exceed 4 m/ s. To obtain a good performance of a wind turbine, it must be a wind speed in the range of 5.37 to 9.37 m/s. This can be considered inappropriate for conversion systems of wind energy (stable averages would be more appreciable to ensure a stable electricity production).

C. Village Load Data Description

The hourly electrical load data for the year 2011 was obtained for the village and load analysis was performed. The load considered is for a village of 480 persons with power consumption around 0.26kWh/d per person. The average daily consumption is shown in Fig. 3. This shows that the consumption is important from 08:00 to 20:00 h. The consumption peak value for the day was 6.669 kW at 19:00 h. The annual average daily consumption was 124.8 kWh/day.
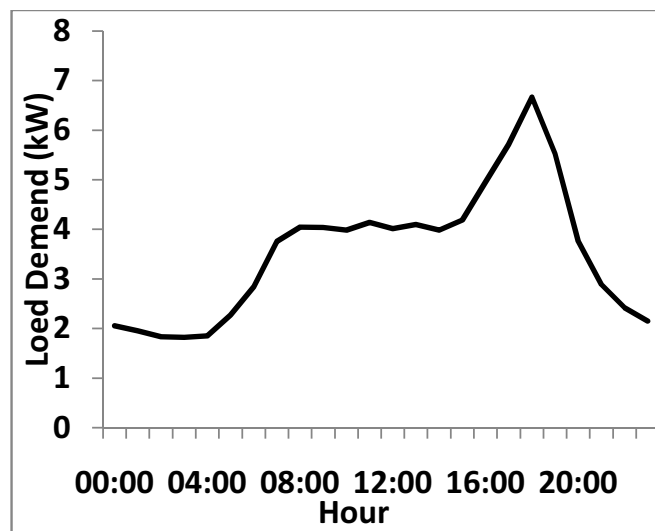

Fig. 3 Typical day load demand for the village

III. WIND-PV-DIESEL HYBRID POWER SYSTEM

Hybrid power systems can consist of any combination of wind, photovoltaic, diesel, and batteries. Such flexibility has obvious advantages for customizing a system to a particular site's energy resources, costs, and load requirements. In the present case, a wind-pv-diesel hybrid power system and a power converter is used to design and meet the load requirements of the village under investigation. The schematic diagram of the wind-pv-diesel hybrid model used in this study is depicted in Fig. 4. The hybrid power system optimization tool HOMER developed by NREL has been used in the present study.
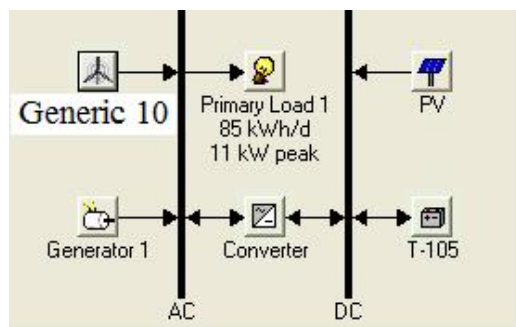

Fig. 4 Wind-pv-diesel hybrid model used in the study

A. HOMER Software Hybrid Power System Modeling Tool

HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms allow the user to evaluate the economic and technical feasibility of a large number of technology options and to account for uncertainty in technology costs, energy resource availability, and other variables. HOMER models both conventional and renewable energy technologies.

B. HOMER Software Input Data

The main input data include the hourly mean wind speed, hourly total solar radiation and load data; technical specifications and cost data of diesel generators, wind turbines, photovoltaic modules, power converters and economic parameters. The details of solar radiation and load data has been given above in the preceding paragraphs and the values of remaining data are given below:

➢ Wind turbines:
Wind turbine sizes considered (kW) = 0 and 10.
Cost of wind turbine (US$) =20,000
Cost of replacement of wind turbine (US$) = 6,259
Operation and maintenance cost (US$/turbine/year) = 6,392
Operation life of the wind turbines (Years) = 25
➢ Photovoltaic modules:
Photovoltaic sizes considered (W) = 0 and 180
Cost of photovoltaic array (US$) = 48,000
Replacement cost of photovoltaic array (US$) = 13,096

Photovoltaic modules were considered as fixed Working life of photovoltaic panels (years) = 20
➢ Power converter:
Power converter sizes considered (kW) = 0 and 8.4
Cost of power converter (US$) = 6,000
Replacement cost of power converter (US$) = 2,504
Operation and maintenance cost of power converter (US$/year) = 6770
➢ Batteries:
Batteries sizes considered (kW) = 0 and 9.2
Operation life of the Batteries (Years) = 10
Capital cost (US$) = 16,800
Operation and maintenance cost (US$) = 14,317
➢ Diesel generators:
Generator sizes considered (kW) = 0 and 18.5
Life time operating hours (year) = 8.23
Capital cost (US$) = 37,500
Replacement cost (US$) = 4,912
Operation and maintenance cost (US$) = 17,478

IV. RESULTS AND DISCUSSIONS

Once the previously described specifications have been input to Homer, this software performs calculations to determine the best combination that technically and economically meets our demand. The results are summarized in Fig. 5 where the optimal systems are ranked according to their technical and economic feasibility.

Fig. 5 The optimization results with the optimum systems ranked

The proposed wind-pv-diesel hybrid system was able to meet the energy requirement of the village of Ain Merane with 54% of renewable energy penetration in to the existing diesel only power system with average wind speed of 5.37 m/s and global solar radiation of 5.28 kWh/m^2/d. Table I summarizes the energy contribution by wind, solar pv system and the existing generator. As seen from this table, 54% of the energy is supplied by the wind and solar pv system and the remaining 46% by the diesel generator.

TABLE I
ENERGY CONTRIBUTION OF DIFFERENT ENERGY SOURCES

Components	Production (kWh/year)	Fraction
Wind turbine	10.904	29%
PV	9.531	25%
Generator	17.627	46%
Total	38.063	100%

The results obtained in Fig. 6 are calculated taking into consideration the price of diesel set by the Algerian

government. It should be mentioned that this price is subsidized and that the real price is three times more. To take this into consideration and to better visualize the effects of both wind speed and diesel price; a sensitivity analysis over the two parameters has been carried out and the results are depicted in Fig. 6.
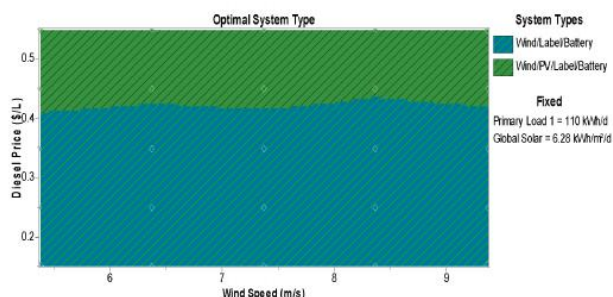

Fig. 6 Sensitivity analyses for wind speed and diesel price parameters

For the site of Aine Merane, the results point out that a Wind-pv-diesel-battery based system is the best choice for a diesel price between 0.4 and 0.55$ (Green region in Fig. 7) and a Wind-diesel-battery is the best choice for a price between 0.2and 0.4$.

TABLE II
ANNUAL GHG EMISSIONS FROM DIESEL ONLY AND HYBRID POWER SYSTEMS

Pollutant	Emissions (kg/yr)	
	Diesel only	54% RE penetration
Carbon dioxide	77656	17365
Carbon monoxide	192	42.9
Unburned hydrocarbons	21.2	4.75
Particulate matter	14.4	3.23
Sulfur dioxide	156	34.9
Nitrogen oxides	1710	383
Total GHG	79749.6	17833.78

The proposed wind-pv-diesel hybrid power system with 54% renewable energy penetration could avoid addition of 62 tons of GHG equivalent of CO_2 annually in to the local atmosphere of the village under consideration. The reduction in the quantity of different air pollutants for 54% renewable energy penetration compared to that diesel only power plant is given in Table II.
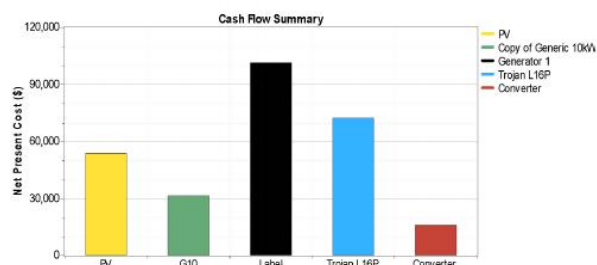

Fig. 7 Cash flow summary of various components of the hybrid
power system

The total costs of each component of the hybrid power systems, including mainly the wind turbines, pv panels, generator, and power converter, are shown in Fig. 7. It is evident, that bulk of the total net present cost (NPC) is accounted for diesel generating sets and the least for converter. The capital cost of the proposed hybrid power system was worked out to be 128,080US$ with replacement, O & M, and fuel cost of 104676US$, 45875US$, and 12,6451US$ respectively.

V. CONCLUSION

In this study, the optimization of a hybrid stand alone Wind/Solar/Diesel based energy system has been considered for the site of Aine Merane. The optimization task has been carried using the powerful tool HOMER which successfully determined the best technical and economical system to adopt for the site. The work has successfully demonstrated that the region possess a large potential of both solar and wind energies. It has been also found that hybrid renewable energy system present a better alternative than those connected to grid especially in remote areas.

REFERENCES

[1] D.G. Infield, "An overview of renewable energy technologies with a view to stand alone power generation and water provision", Presented at the Water and Sanitation in International Development and Disaster Relief (WSIDDR) International Workshop Edinburgh, Scotland, UK, 28–30 May 2008. Published by Elsevier.
[2] Yang H, Wei Z, Chengzhi L. Optimal design and techno-economic analysis of a hybrid solar-wind power generation system. Applied Energy 2009; 86:163.
[3] D. Saheb-Koussa, M. Haddadi and M. Belhamel .Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria. Applied Energy 86 (2009) 1024–1030.
[4] Yang H, Zhou W, Lu L, Fang Z. Optimal sizing method for stand-alone hybrid solar-wind system with LPSP technology by using genetic algorithm. Solar Energy 2008;82:354.
[5] F. Chellali , A. Khellaf, A. Belouchrani, and A. Recioui, "A contribution in the actualization of wind map of Algeria", Renewable and Sustainable Energy Reviews, Vol. 15, 2011, pp. 993–1002.
[6] Dihrab SS, Sopian K. Electricity generation of hybrid PV/wind systems in Iraq. Renewable Energy 2010;35:1303-7.
[7] Nfah EM, Ngundam JM, Tchinda R. Modelling of solar/diesel/battery hybrid power systems for far-north Cameroon. Renewable Energy 2007;32:832-44.
[8] Ekren O, Ekren BY, Ozerdem B. Break-even analysis and size optimization of a PV/wind hybrid energy conversion system with battery storage - a case study. Applied Energy 2009;86 (7-8):1043-54.
[9] D. Connolly, H. Lund, B.V. Mathiesen and M. Leahy, "A review of computer tools for analysing the integration of renewable energy", into various energy systems", Applied Energy, Elsevier Ltd. 2009.
[10] Juhari Ab. Razak, Kamaruzzaman Sopian, Yusoff Ali, Mohammad Ahmed Alghoul, Azami Zaharim And Ibrahim Ahmad, "Optimization of PV-Wind-Hydro-Diesel Hybrid System by Minimizing Excess Capacity", European Journal of Scientific Research, 2009.