Energy Conversion and Management 91 (2015) 267–279

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Determination of the optimum design through different funding scenarios for future parabolic trough solar power plant in Algeria

Ameur Trad [a,b,*], Mohand Ameziane Ait Ali [a]

[a] Mechanical Engineering and Development Laboratory, Mechanical Engineering Department, National Polytechnic School of Algiers, ENP, 10 Avenue Hassen Badi, El-Harrach 16200, Algeria

[b] Unité de Développement des Equipements Solaires, UDES, Centre de Développement des Energies Renouvelables, CDER, 42415 Tipaza, Algeria

ARTICLE INFO

Article history:
Received 24 August 2014
Accepted 3 December 2014
Available online 24 December 2014

Keywords:
Fuel consumption
LEC
Optimum design
Solar power plant size
Sensitivity scenario
Storage capacity

ABSTRACT

The purpose of this study is to determine an optimum design for a projected parabolic trough solar power plant (PTSPP) under Algerian climate through different funding scenarios. In this paper, seven different (d1–d7) designs for PTSPP have been developed for the Naâma site. Plant size, technology type, storage capacity, location of the plant, Operation & Maintenance (O&M) costs, replacement costs, fuel consumption, net CO_2 emission, levelized electricity cost, net power generation, specific investment costs and discount rate are the basis factors to determine the optimum sustainable design for PTSPP. The most attractive designs of each base technology were selected as D1, D2 and D3. The preferable design of three funding scenarios was finally selected on economic, financial and sensitivity analysis. It is finally concluded that, under the most favorable economic conditions allowed in this study, design D3 is the most advantageous in terms of benefit to cost ratio: its power output will be 100 MW_{el} with 8 full load hours thermal energy storage. It was also found that for design D3 under funding scenario S2, the project will require an upfront grant of 396 MEUR. This corresponds to around 56% of the total investment cost and the payback period will be approximately 7 years.

1. Introduction

World primary energy demand is expected to continue to increase at 1.5–1.8% per year according to various scenarios and assumptions, depending mostly on emerging economies demands of China, India and Brasil [1]. Known reserves of fossil fuels are shortest for oil, then natural gas and coal [2]. Algeria is an oil and gas producing country whose economy is largely supported by its energy exports. In 2011, she produced 157.7 MToe of hydrocarbons of which 79.4 MToe are liquids and 78.2 MToe natural gas, in decrease of 3.1% compared to 2010 (respectively 162.6, 81.7, and 80.8). For the year 2011, exports were 83.1 MToe of which 48.2 MToe were liquids and 33.8 natural gas; these figures are in slight decrease compared to those of 2010: respectively 85.7, 49.9 and 35.8. Algeria domestic energy consumption continues to increase drastically: the overall consumption increased from 43.8 MToe in 2010 to 46.1 MToe in 2011 (liquid fuels increased by 7.1%, natural gas by 5.3%, electricity by 8.2%). If these trends continue (a 3.1% decrease of production and a 5.0% increase of consumption) Algeria will have no hydrocarbons left to export after the year 2028. Even if production decreases at a slower rate after 2014, thanks to potential new discoveries, the outlook will

Abbreviations: AEC, Algerian Energy Company; AH, Auxiliary Heating; CAPEX, Capital Expenditures; CTFC, Clean Technology Fund Conditions; CSP, Concentrating Solar Power; DBL, Development Bank Loan; DC, Dry Cooling; DLR, German Aerospace Center; DNI, Direct Normal Irradiation; DSA, Demand and Supply Analysis tool; DSCR, Debt Service Coverage Ratio; DUC, Dynamic Unit Cost; EIRR, Economic Internal Rate of Return; ET, Euro Trough; FAT, Financial Analysis Toolkit; FIRR, Financial Internal Rate of Return; FiT, Feed-in-Tariff; FLH, Full Load Hour(s); FNPV, Financial Net Present Value; GHI, Global Horizontal Irradiation; HTF, Heat Transfer Fluid; IRR, Internal Rate of Return; ISCCS, Integrated Solar Combined Cycle System; kDZD, Kilo Algerian Dinar; kEUR, kilo Euro (Currency); LEC, levelized electricity cost; LNG, Liquefied Natural Gas; MEM, Ministry of Energy and Mining; Mtoe, Million tons of oil equivalents; NEAL, New Energy Algeria; NPV, Net Present Value; O&M, Operation & Maintenance; OPEX, Operational Expenditures; PV, Present Value; RE, Renewable Energy; RoE, Return on Equity; SCA, Solar Collector Assembly; SF, Solar Field; SONATRACH, Société Nationale pour la Recherche, la Production, le Transport, la Transformation, et la Commercialization des Hydrocarbures; SONELGAZ, Société Nationale de l'Electricité et du Gaz; SPE, Société de Production d'Electricité; SPP1, Solar Power Plant One; TES, Thermal Energy Storage; TPP, Thermal Power Plant; USD, Dollar of the United States of America (Currency).

* Corresponding author at: Mechanical Engineering and Development Laboratory, Mechanical Engineering Department, National Polytechnic School of Algiers, ENP, 10 Avenue Hassen Badi, El-Harrach 16200, Algeria. Tel.: +213 660937460.

E-mail address: hotflow12@yahoo.fr (A. Trad).

http://dx.doi.org/10.1016/j.enconman.2014.12.013
0196-8904/

not change drastically without a drastic change course of action. Clearly, Algeria needs to slow down its consumption and invest significantly in new sources of primary energy, the most promising of which is photovoltaic and thermo solar conversion. Algeria official energy policy has set ambitious RE production objectives a decade ago in 2004, but progress has been slow so far chiefly because of cheap domestic energy pricing history (about 4 US cents/kW h, 90 US cents/gallon for premium gasoline and 50 US cents/gal of gas oil). Many countries have formulated solar energy policies to reduce their dependence on fossil fuel and increase domestic energy production from solar energy [3]. In order to achieve these goals, there is a need to provide comprehensive studies for economically viable, environmentally suitable scenarios and policy recommendations towards addressing energy requirements for North African countries [4,5]. The adoption of renewable energy sources as a viable and trusted alternative in maintaining the desired quality of life for future generations is a challenge that can be achieved [6].

In order to compare prospects of renewable energy development applications in Algeria, reliable figures were obtained from the German Aerospace Centre (DLR). Fig. 1(a) and (b); they show the forecasted capacity and development of electricity generation between the years 2000 and 2050.

When looking at produced capacity of renewable energy in GW, it can be seen in Fig. 1(b) that CSP is going to experience a strong increase from 0.67 GW in 2020 to 7.3 GW in 2030. The number will even more than double in the following decade as it will rise from 7.3 to 19.9 GW. The positive development of CSP is expected to hold on in the years after as well.

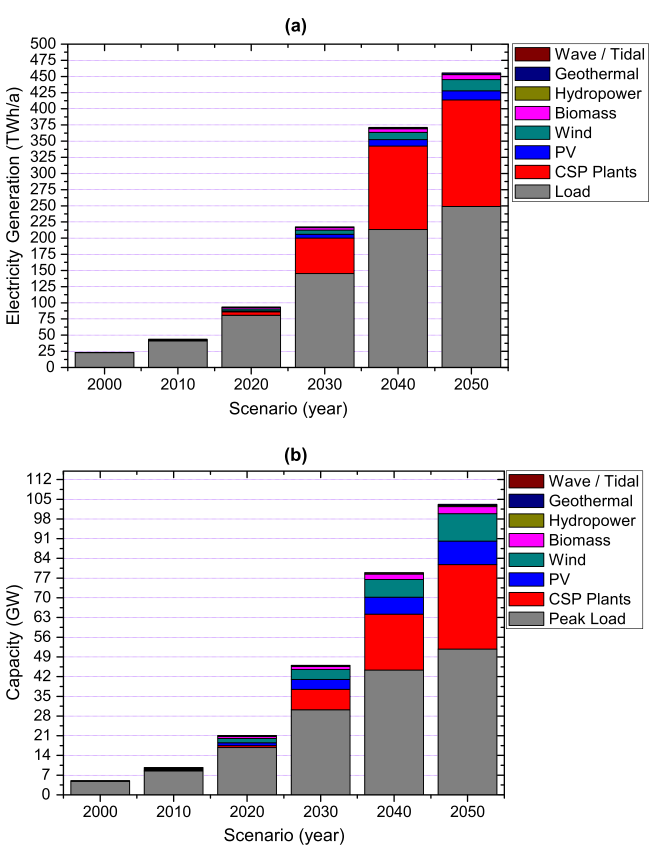

Fig. 1. Renewable generation in Algeria: (a) forecasted development of electricity generation TW h/a; (b) forecasted expansion of capacity in GW [7].

1.1. Solar power development in Algeria

Algeria has the potential to become a major contributor in thermo-solar energy production in the near future. Algeria has developed a national program for the period 2011–2030 to promote concrete actions in the fields of energy efficiency and RE in line with the approach recently adopted by the Ministry of Energy and Mining (MEM) and government [8]. The national energy companies in charge of the implementation of the RE program are: SONATRACH, SONELGAZ, AEC and NEAL. In addition, the company plans to export 6000 MW solar energy electricity to Europe using transmission lines between Morocco and Spain by 2020. Algeria's first CSP project of Hassi R'mel is currently operational since the end of 2010 [9]. The 150 MW, 425 million USD project is an Integrated Solar Combined Cycle (ISCC) with a solar share of 30 MW_{el} net (or 35 MW_{el} gross). The power plant is supplied by solar thermal power (parabolic trough) and natural gas. Its parabolic mirrors have a total aperture area of 180,000 m^2. Moreover, NEAL plans to commission three more plants using the same hybrid technology with 400 MW capacity each. Depending on the construction progress of the current project in Hassi R'mel (SPP IV) and Meghaïer (SPP II), the two further hybrid power plants could be launched in 2018 [10,3].

Note that all CSP projects currently operational or under construction in Algeria are using hybrid technology system without storage. It is the peculiarity of pre-transition Algerian program: CSP plants for medium capacity, connected to the grid which benefit to preferential tariffs of natural gas.

1.2. Objectives of the study

Seven different basic plant designs (d1–d7) have been simulated. In all cases power block size, storage capacity and/or amount of auxiliary heat were predetermined. For each configuration the annual thermal and electrical output was calculated for different sizes of the solar field. After the determination of the annual yield, the next step is the integration of cost calculations. They define the optimum field size and the most promising designs to be further investigated.

2. Plant site characteristics

Ten prospective sites were presented for CSP assessment using solar resources based on satellite data from METEONORM and SWERA. Two sites close to Kenadsa and Naâma showed favorable conditions with the latter site finally selected for further evaluation because of better accessibility. Table 1 shown favorable conditions of the Naâma site.

2.1. Meteorological conditions and solar resource of the site

The most important informations to obtain from the meteorological stations are: Solar resource (DNI), if not recorded GHI and DHI; Temperature (daily min, max and average values); Wind (daily min, max and average values; main wind directions; seasonal winds; heavy storms); Humidity (relative humidity, daily min, max and average values); Precipitation (daily rainfall and snowfall hail).

For the selected site the database indicates an annual total of Direct Normal Irradiation (DNI) 2307 kW h/m^2. This data is calculated on the basis of satellite imagery and atmospheric modeling. The model for the surface radiation calculation shows methodological errors or uncertainties of up to 10% for Global Horizontal Irradiance (GHI).