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The potential of concentrating solar power (CSP) for electricity generation in Libya

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ABSTRACT

The rapid increase in energy demand and the limited resources of fossil fuel as well as the environmentally damaging effects, drive the world to find new options for sustainable electricity generation, which is represented by renewable energies. Concentrating solar power (CSP) is one of the most promising technologies in the field of electricity generation to tackle this issue with a competitive cost in the future. This paper presents an investigation of the potential of implementation of CSP plants in Libya. The socio-economic context, current energy situation of the country and different types of CSP plants are discussed. Moreover, an assessment of site parameters required for CSP plants including solar resources, land use and topography, water resources and grid connections are investigated in detail. In addition, thermo-economic simulation of a 50 MW parabolic trough power plant is performed. The simulation is conducted based on meteorological data measured by the weather station installed at the Centre for Solar Energy Research and Studies (CSERS) in Tajoura city. The performance results are compared with the reference plant Andasol-1 in Spain. Even though the proposed plant is located on the North coast where solar resources are at their minimum compared with other regions of the country, the outcome of the study proves that Libya is not only suitable but it can be economically competitive in the implementation of CSP technology.

1. Introduction

The rapid growth in global energy consumption is leading to a great increase in energy demand. It is estimated that electric energy consumption will double in the next 15–20 years. This demand is due to an increase in population and the scope of wealth [1]. Fossil fuels supply about 80% of the total primary energy consumed worldwide [2]. Considering the limited sources of fossil fuels and their negative impact on the environment, which is illustrated in direct pollution and gas emissions, the challenge which faces the global community is to find alternative energy sources as a substitute for fossil fuels as well as satisfying the increase in energy demand [3,4].

Renewable energy sources are considered a valuable alternative source of energy since they are sustainable, cheap and environmentally friendly [5]. Concentrating solar power (CSP) plants is one of the most attractive technologies to produce electricity especially in countries that are rich in solar energy resources. CSP technology has an increasing attention due to the durability and dispatchability of these systems. Globally, the total installed capacity is about 5 GW with large-scale solar thermal power plants connected to the grid. Spain and USA are the leading countries in this technology in which they have 61% and 18% respectively of the total generated capacity. New markets have been emerged in countries like South Africa, Morocco and Chile due to their solar recourses and political dedication of their governments. This technology depends on converting solar arrays into heat that can drive conventional turbine generators or engines. The CSP systems range from small isolated units producing few kilowatts (kW) to up to grid-connected power plants of megawatts (MW) [6–10].

Libya is an oil- rich country nevertheless it is trying to reduce its dependency on fossil fuels in order to develop a more sustainable and clean source of energy and income. Fortunately, Libya has an enormous potential for solar energy which it is about 1,759,540 km^2 area at the centre of North Africa. It has a long coast of 1900 km on the Mediterranean Sea and the vast majority of the country is desert with a

Abbreviations: CSERS, Centre for Solar Energy Research and Studies; DNI, Direct Normal Irradiance; GDP, Gross Domestic Production; GHI, Global Horizontal Irradiance; HTF, Heat Transfer Fluid; LCOE, Levelized Cost of Energy; LFR, Linear Fresnel Reflector; SAM, System Advisory Model

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high potential for solar radiation [11–13]. Based on the German Aerospace Centre, each square kilometre (km^2) of this region receives solar energy equivalent of 1.5 million barrels of crude oil annually [14].

This review paper is an attempt to assess the potential of CSP generation in Libya. It will help for future policy, planning and implementation of this emerging technology in the country. This study would also be useful in attracting the investments in development CSP based power plants in the Sahara Desert and MENA region. A review of socio-economic and energy situation is investigated to highlight the energy cries in the country. It is in the context a description of different CSP systems has been also presented. A detailed assessment of the factors effecting the deployment of this technology is conducted. In addition, a thermo-economic performance analysis of a 50 MW parabolic trough based power generation is presented and compared with the reference commercial plant Andasol-1 installed in Spain.

2. Socio-economic context

The population and population growth rate are one of the major driving forces for electrical energy demand in Libya. The population of Libya has grown from 5.3 million in 2000 to about 7 million in 2015 with an average growth rate of 1.7%. Consequently, the population is expected to reach to 8 million in 2020 and this statistic does not take into account the foreign labours and immigrants [14,15].

Regardless of the political instability situation in Libya since 2011, the economic growth represents the second main driving force for the electric energy demand in the country. The total GDP of Libya in 2000 was around 0.6 million $/capita and grew to reach 0.9 million $/capita in 2013. The average long term per capita GDP growth rate is 3.8% a year. In addition, forecasting investigations expect the GDP of Libya to reach approximately 13 million $/capita in 2020 [16,17].

The economic structure of the country consists of three main sectors: oil and gas export, services sector, and agriculture. In 2012, exports of oil, natural gas and their derivatives represented about 78% of the total economy of the country. In the same year, the services sector and agricultural activity represented 20% and 2% respectively of the total economy of the country [17].

3. Energy situation in Libya

The growth in both population and economy put increasing pressure on energy generation and demand all over Libya. This electric demand requires further significant investments in electricity generation including power lines and power stations. Libya's electric demand is illustrated in Fig. 1 based on the data obtained from the General Electric Company of Libya. It can be observed that electric demand is growing rapidly, around 8–10% annually, and is therefore expected to reach about 9 GW by 2020 [11,12,18,19].

The General Electric Company of Libya (GECOL), a government owned company, is responsible for the operation of the entire power sector in the country. All the power plants in Libya have been installed and operated by GECOL since it was established in 1984. Libya has a total installed power generation capacity of 6.3 GW [20]. In Libya, most of the electrical energy production comes from fossil-fuelled conventional power plants including gas-turbine, steam-turbine and combined cycle power plants. Gas turbine and combined cycle power plants have a share of 43% and 37% respectively in total installed power capacity; the share of steam power plants is 20% in total. Furthermore, some small diesel power plants are also used to contribute to the energy supply, especially in remote areas [14,16,18].

The growth in electrical power demand will out-strip production capacity and so GECOL plans to build new combined cycle and steam cycle power plants. In addition to increasing generation capacity, GECOL is also planning to upgrade and expand the country's power transmission grid. Table 1 shows current and planned electricity generation infrastructure expansion [20]. The only way to reduce the dependency on fossil fuel, and the environmental problems caused by combustion of fossil fuels, is to use renewable energy sources that are sufficiently available in Libya, particularly solar energy. Libya has planned to develop renewable energy for electricity generation see Table 2. The main target is to produce 10% of total electricity demand from renewable energy by 2025 which is equivalent to 2.219 GW. However, this plan was interrupted in 2011 by the political uprising [21].

4. Concentrating solar power systems CSP

CSP systems consist of two main parts namely the solar field and the power block. The solar field concentrates direct solar radiation received from the sun and converts the solar energy to thermal energy. Consequently, the heat is used to produce steam which will drive the power block to generate electricity. CSP plants can be classified based on the types of solar collectors used into two groups. The first is line focus technologies which concentrate the sun's heat along the focal length of the collector represented in a parabolic trough and linear Fresnel reflector. The second is point focus technologies which concentrate the sun's heat on a point including a power tower and parabolic dish [22–24].

4.1. Parabolic trough system

The parabolic trough solar power plant represents the most mature, successful and developed concentrating solar power technology for electricity generation. A schematic diagram of a parabolic trough solar power plant is illustrated in Fig. 2. The solar field assembles of multiple parabolic trough solar collectors. The parabolic trough collectors consist of an array of curved mirrors placed inside each of the parabolic troughs. The solar collectors are filled with heat transfer fluid (HTF), such as molten salt and Therminol-VP, or with water in case of direct steam generation systems. The solar collectors are arranged in a series configuration known as loops and oriented in a North-South direction in order to track the sun from East to West. Thermal energy storage (TES) can be used with solar power plants to ensure continuity in electricity production. Normally the capacity of thermal energy storage is in the range of several hours in which it is filled with HTF during the day and emptied after sunset to maintain electricity production even after sunset. The thermal energy collected by the solar field is used by the power block to generate steam by using a heat exchanger. The power block normally used in solar power plants is a regenerative Rankin cycle which uses a steam turbine generator to produce electrical energy. These systems have the flexibility to integrate with other conventional or renewable energy systems [3,24,25]

4.2. Linear Fresnel reflector system

The general configuration of a linear Fresnel power plant is quite similar to that in parabolic trough plants. The main difference between them is the solar collectors used in the solar field. A linear Fresnel Reflector (LFR) consists of an array of linear or curved mirror strips, behaving as a Fresnel lens, which concentrates solar radiation on to a fixed receiver mounted on the top, see Fig. 3. Secondary concentrator can be used with these systems to increase the concentration ratio. Consequently, the collected thermal energy is then used to operate the conventional power cycle. The main advantage of this technology is the simplicity and the low cost of its components [2,24,26].

4.3. Solar tower system

This system is also called "central receiver technology". The solar field consists of a number of circular two axis tracking arrays. Each array is a number of flat or slightly bent heliostats. The heliostat is assembled of a large number of sun-tracking mirrors, which concentrate