Renewable Energy 49 (2013) 96–100

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Influence of solar energy resource assessment uncertainty in the levelized electricity cost of concentrated solar power plants in Chile

Matías Hanel, Rodrigo Escobar*

Department of Mechanical and Metallurgical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, Chile

A R T I C L E I N F O

Article history:
Available online 21 March 2012

Keywords:
Solar power
Chile
Parabolic trough

A B S T R A C T

The deployment of renewable energy power plants is a priority of the Chilean government. A mandatory quota system requires that 5% of the electricity generated in the country must come from renewable energy sources, gradually increasing to 10% by 2024. As of 2010, solar energy has received attention only for small-scale future demonstration projects. Concentrated solar power (CSP) plants are an interesting option for the country, especially when considering the high levels of solar radiation and clearness index that are available in northern Chile. Here we present a thermal and economic analysis of CSP plants of the parabolic trough type, comparing five different configurations including thermal energy storage and fossil fuel backup. The electricity yields are obtained from hourly simulations that consider radiation levels, solar field, and power plant characteristics. An economic model that includes the costs of construction, operation and maintenance allows predicting the levelized electricity cost (LEC) as a function of plant configuration and location. The results indicate that the plants can produce dispatchable electricity at a cost that is competitive and inversely proportional to radiation levels. A sensitivity analysis is conducted in order to determine the influence of solar field area and radiation levels, and the optimal plant configuration and solar field area are obtained as a result.

1. Energy in Chile

The main energy sources that the country utilizes are oil and its derivates, coal, and natural gas. The country does not produce any of them in significant quantities, and it does not hold any meaningful reserves that could be explored and exploited in the future. As of 2009, Chile relies on fuel imports to meet its growing energy demand, which combined with limited fossil fuel resources make Chile a growing net importer of energy. Renewable energy sources in use by the country comprise only hydroelectricity and wood-based biomass, accounting for 24% of primary energy consumption, while non-renewable sources account for the other 76%. The electricity sector has begun to rely heavily on coal-fired power plants, with up to 3 GW of capacity being planned to enter the system in the next three to five years. Thus, Chile is not only staying dependent on imported energy, but is also switching to more expensive sources such as liquefied natural gas, and to fuels of greater environmental impacts such as coal. These two concrete actions that Chile is taking in order to secure energy supply go directly against the sustainable development definition. Therefore, it is of critical importance for the country to achieve three primary strategic goals: first, to provide adequate energy supplies in order to continue its economic growth; second, to ensure that imported energy is accessed through international markets to satisfy any requirements that cannot be met by indigenous production; and third, to ensure the development of indigenous energy sources at a sufficient rate such as needed for the substitution of imported energy resources in order to rapidly achieve energy security and a degree of energy independence.

Starting on 2010, a new law has been passed which requires electricity distributors to provide 5% of their energy sales from renewable energy sources, at average bided prices, increasing this contribution to 10% by 2024. The government hopes to promote the use of renewable energy for electricity generation, as a result of modifying the electricity sector law, effectively removing barriers for the incorporation of renewable energy plants. The law has resulted in several wind and biomass energy power plants being planned and entered into the environmental impact assessment mechanisms. In general, Chile is thought to be abundantly endowed with renewable energy but no large scale renewable energy resource assessment has been conducted, and in particular for wind and solar. Therefore, any energy planning effort that considers these renewable sources is seriously impeded for the time being. In the case of solar energy, large scale systems are not being planned

* Corresponding author. Tel.: +56 2 3545478.
E-mail address: rescobar@ing.puc.cl (R. Escobar).

0960-1481/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.renene.2012.01.056

or even discussed. Regarding the power generation sector, the solar thermal power plant technology is scarcely known. Solar energy development in Chile is small, mostly focusing on water heating applications for the residential sector. The total contribution of solar energy to the primary energy consumption of Chile is negligible [1].

1.1. Parabolic trough plants

It has been argued that Concentrating Solar Power (CSP) technologies are the most convenient in economics terms, with their cost projections being such that they are becoming competitive with traditional power plants even today [2,3]. The Parabolic Trough Collector (PTC) power plant is the most developed and proved, with commercial use in the US since 1985, and new plants being built in Spain, USA, Morocco, Algeria, and plans to build in other countries as well. The PTC concept is simple, and basically focuses direct solar radiation in an absorber tube, which is located at the center of an evacuated glass tube for minimizing thermal losses. The concentration factors can be as large as 90 [4], and commercial systems are available from 14 to 80 MW. The HTF is heated in the absorber element of the concentrator array to temperatures close to 400 °C, and then transfers thermal energy to the power block through a heat exchanger. A fossil-fired boiler can supply backup heat during non-sunlight hours, or can stabilize the steam thermodynamical state in order to maintain a constant power generation. Given sufficient solar input, the plants can operate at full rated power using solar energy alone. Most of the research on PTC plants is focused on achieving higher plant availability and efficiency, by means of thermal energy storage (TES), improvement of the HTFs, better prediction of available solar radiation, and direct steam generation (DSG) techniques [2–5] (Fig. 1).

The PTC plants are becoming very competitive in the actual context of high energy prices and environmental pressures [6–8]. A great effort has been devoted to the development of adequate steps for cost reduction, defining several research priorities with an estimated cost reduction potential of up to 40%: increase the scale to plants larger than 50 MW, improve concentrator structure and assembly, utilization of advanced energy storage schemes, advanced reflectors, increase HTF temperature, and reduction of parasitic loads [9,10]. Improved assessment of solar energy resource is perceived to be the first step in developing a technical program that will lead to proper installation of CSP plants with economical feasibility. An erroneous input for direct solar radiation can lead to an erroneous size of collector field, which can result in severe financial difficulties for the plant during operation. In this context, computational simulation is perceived as the best tool for properly estimating collector field size during the design stages of CSP PTC plant planning [10,11]. Since all research and commercial application of CSP plants has been done in geographical regions that receive a lower average of solar energy than Chile [4,12] (Fig. 2), this seems to indicate that the country presents a distinctive advantage for CSP utilization, and that PTC plants installed in Chile could display a better performance than what has been achieved in other countries.

2. Potential in Chile for CSP plants

The potential in Chile for CSP plants has not being determined on a large scale. It is possible to affirm that the Atacama Desert in the northern part of the country is one of the best regions for solar energy, based on energy density data from several sources [4,12,13]. Chilean skies in the northern part of the country exhibit the highest number of clear days of any region in the world, and as such have attracted many astronomical observatories. Consumption centers in the northern part of the country are mostly mining industries, which consume the highest share of power generation [1] with fundamentally constant demand. And the region is a desert, with ample plains and flat, unused terrain. Therefore, all three basic conditions for the development of solar thermal power plants are met in the northern region of Chile: high levels of direct solar irradiance during most of the year, availability of flat terrain, and short distance to consumption centers [2].

However, the first necessary step in order to adequately perform energy planning activities and especially solar energy conversion systems design is to have precise solar energy availability databases of low uncertainty, which unfortunately is not the case in Chile. Although several data sources exist, they either lack on spatial and

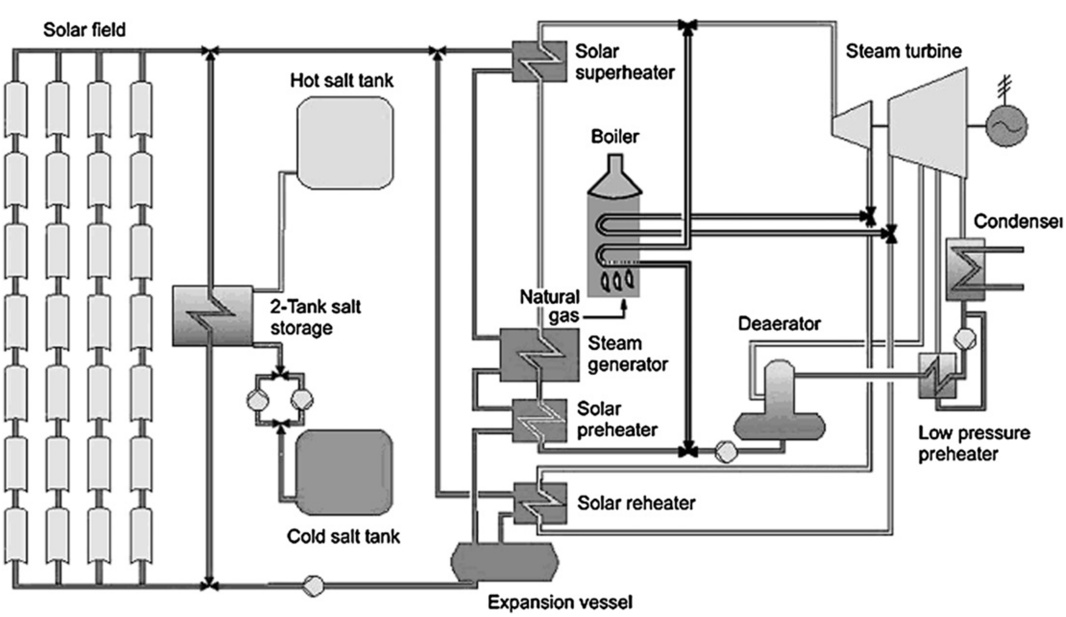

Fig. 1. Schematic of a PTC CSP plant of the SEGS/LUZ systems, with thermal energy storage and auxiliary, fossil fuel fired backup boiler. From [16].