Renewable Energy 61 (2014) 81–95

Contents lists available at SciVerse ScienceDirect

Renewable Energy

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

Economic implications of thermal energy storage for concentrated solar thermal power

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ARTICLE INFO

Article history:
Received 29 December 2011
Accepted 6 August 2012
Available online 13 September 2012

Keywords:
Concentrated solar power
Thermal energy storage
Parabolic trough
Levelized cost of energy

ABSTRACT

Solar energy is an attractive renewable energy source because the sun's energy is plentiful and carbon-free. However, solar energy is intermittent and not suitable for base load electricity generation without an energy backup system. Concentrated solar power (CSP) is unique among other renewable energy options because it can approach base load generation with molten salt thermal energy storage (TES). This paper describes the development of an engineering economic model that directly compares the performance, cost, and profit of a 110-MW parabolic trough CSP plant operating with a TES system, natural gas-fired backup system, and no backup system. Model results are presented for 0–12 h backup capacities with and without current U.S. subsidies. TES increased the annual capacity factor from around 30% with no backup to up to 55% with 12 h of storage when the solar field area was selected to provide the lowest levelized cost of energy (LCOE). Using TES instead of a natural gas-fired heat transfer fluid heater (NG) increased total plant capital costs but decreased annual operation and maintenance costs. These three effects led to an increase in the LCOE for PT plants with TES and NG backup compared with no backup. LCOE increased with increasing backup capacity for plants with TES and NG backup. For small backup capacities (1–4 h), plants with TES had slightly lower LCOE values than plants with NG backup. For larger backup capacities (5–12 h), plants with TES had slightly higher LCOE values than plants with NG backup. At these costs, current U.S. federal tax incentives were not sufficient to make PT profitable in a market with variable electricity pricing. Current U.S. incentives combined with a fixed electricity price of $200/MWh made PT plants with larger backup capacities more profitable than PT plants with no backup or with smaller backup capacities. In the absence of incentives, a carbon price of $100–$160/tonne CO_{2eq} would be required for these PT plants to compete with new coal-fired power plants in the U.S. If the long-term goal is to increase renewable base load electricity generation, additional incentives are needed to encourage new CSP plants to use thermal energy storage in the U.S.

1. Introduction

Solar energy is an attractive renewable energy source because the sun's energy is plentiful and carbon-free. However, solar energy is intermittent and not suitable for base load electricity generation without an energy backup system. Concentrated solar power (CSP) is unique among solar energy technologies because it has been operating commercially at utility-scale since 1985 [1], and it generates electricity with a thermal power cycle similar to that used in conventional fossil fuel-fired power plants. One advantage of this type of power cycle is that the thermal inertia in a CSP system is generally sufficient to sustain energy production during cloudy periods of up to a half hour [2]. Moreover, thermal energy can be stored for later use at a low cost relative to a backup system that uses batteries; or it can be combined with an on-site fossil fuel backup system. Both of these options have the ability to increase the capacity factor (ratio of annual electricity generation to potential electricity generation) of a CSP plant and thus increase its viability as a base load generator. The southwest region of the United States has the potential for up to 200 GW of installed CSP capacity using existing transmission lines [3]. This translates to 12%–20% of current U.S. electricity generation.[1] Given the urgent directive by climate experts to drastically reduce greenhouse gas (GHG) emissions [5], coupled with global concerns over rising

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[1] Assumptions: 4119 TW-hours (TWh) of net electricity generation in the U.S. in 2008 [4]; 30%–50% capacity factor [1].

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http://dx.doi.org/10.1016/j.renene.2012.08.013