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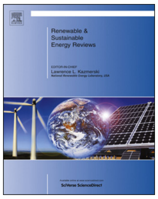

An integrated combined cycle system driven by a solar tower: A review

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ABSTRACT

An integrated solar combined cycle system (ISCCS) basically consists of three major components: a combined cycle gas turbine (CCGT), solar steam generator (SSG) and solar field. The solar tower (ST) technology is one of the potential candidates that can provide the solar field. In this study, progress in the development of a ST-ISCCS has been investigated. It is found that a lot of research attention has been given to the ST technology with some commercial ST power plants operating in different parts of the world. This technology has enormous potential for integration with the ISCCS from thermodynamic and economic perspectives. Nevertheless, the maturity level of the ST technology is lower than that of the parabolic trough concentrator (PTC). Very limited research has been directed toward the development of the ST-ISCCS. In addition, most of the ISCCS power plants in operation today employ the PTC technology with no known commercial ST-ISCCS power plant existing at present (2015). In view of this, it is construed that there are some barriers to the development of the ST-ISCCS technology which broadly fall into three categories: (a) technology maturity, (b) financial and policy, and (c) technical factors. It is concluded that the ST-ISCCS is immature, and so more work is needed to improve its technological readiness.

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1. Introduction

Climate change is one of the global challenges of this century, and it is perceived that energy consumption is the major contributor to this environmental problem. In addition, there is a growing concern about energy security arising from the exploitation of finite resources of energy such as fossil fuels. So, there is need to find alternative sources of energy that are sustainable. In this vein, the application of solar energy in the generation of electricity is perceived to be a promising way of mitigating the negative impacts of climate change and of enhancing energy security. However, solar energy alone, without thermal storage systems, can only provide a diurnal base load due to its intermittent nature. Moreover, the addition of energy storage (thermal or electrical) tends to raise the overall cost of the technology, hence increasing the levelized cost of electricity (LCoE). Nevertheless, with the level of research and development (R&D) activities in solar utilization to produce a base load, concentrated solar power (CSP) technologies have evolved from laboratory scale to commercial applications [1] and more studies are still underway to reduce the technical constraints and investment costs of adopting the systems in the power industry.

It is possible to reduce the cost of solar thermal application in the electricity sector by combining the technology with other sources of thermal energy to run the prime mover to enhance continuous generation of electricity. This can be done by integrating a solar thermal subsystem with a gas turbine (Brayton cycle) or with steam turbine (Rankine cycle) to form a single solar thermal electric power plant (STEP). Each one of the two cycles has limited electric conversion efficiency [2,3], and it can be driven by solar energy.

1.1. *Concentrated solar power*

Concentrated solar power is a technology for generating electricity by using thermal energy from solar radiation focussed on a small area, which may be a line or point. Incoming solar radiation is reflected by a large area of a reflective surface onto the small area (receiver) where it is converted to heat, which is then collected by a working fluid and employed to drive a gas or steam turbine for electricity generation. Concentration of solar radiation on a small area enables the achievement of high temperatures of the working fluid, thereby rendering the CSP technology to be thermodynamically comparable with conventional power plants.

Currently, four CSP technologies have found extensive application in the power industry: parabolic trough concentrators (PTC), linear Fresnel reflector (LFR), solar tower (ST) or central receiver/power tower (as sometimes called), and the parabolic dish concentrators (PDC). It has been shown by Zhang et al. [4] that PTC and LFR systems operate within lower temperature ranges than ST and PDC, with the PDC technology being capable of achieving up to 1500 °C.This variation in operational temperature range could be attributed to differences in the values of solar concentration ratio. The PTC and LFR technologies have low thermodynamic efficiencies compared to the ST and PDC technologies [4–6].

One way of improving the power output of solar thermal systems is through hybridization with other thermal sources. Hence, Peterseim et al. [7] have shown that under hybridization conditions, Fresnel systems are most suitable for feed water preheating, steam reheat and steam boosting at temperatures less than 450 °C while trough systems using thermal oil are more suitable for integrated systems requiring steam temperature less than 380 °C. In the same vein, ST systems employing direct steam generation are most preferable to molten salt ST for application at higher steam temperature above 450 °C. According to Nixon et al. [8], the use of a central receiver in the ST technology results in suppressed thermal transportation and subsequent optimal temperatures of around 500 °C, with stagnation temperatures of about 1750 °C, which is far higher than those of any of the line focusing technologies. Table 1 shows that the PTC technology contributes the highest share of the total installed CSP generation capacity although point focusing technologies possess better thermodynamic characteristics.

Each CSP technology possesses qualities that are distinct and more suitable for a particular purpose. A comparison of the major CSP technologies (PTC, LFR, ST and PDC) is reported by Zang et al. [4] based on the relative cost, land occupancy, cooling water, thermodynamic efficiency, operating temperature range, solar concentration ratio and outlook for improvement. It is noted from their review that the advantages of a given system vary from one feature to another. Consequently, it is not proper to disqualify a given system based on one particular feature as it may be suitable for another application. For instance, whereas ST and PDC technologies are capable of attaining higher output temperatures, PTC systems have been most integrated in moderate temperature steam turbines. Jorgenson et al. [10] reported that the seasonal and daily variations of solar resource availability for equal amount of energy output from PTC and ST plants differs on an annual basis. This is attributed to the fact that the solar resource availability for the ST solar field is relatively constant throughout the year, while that for PTC exhibits a strong seasonal dependence primarily because of the seasonal “cosine” effect. According to EASAC [11] the cosine effect is caused by the low sun elevation angle in winter, which is more pronounced for single-axis tracking parabolic trough collectors compared to the two-axis tracking heliostats used for tower configurations. A summary of individual CSP technology proficiency is presented in Table 2. Similarly, Figs. 1 and 2 show that most of the CSP power plants in operation and under construction are PTC, in agreement with findings of

Table 1
Solar share contribution of installed CSP technologies as on 16 February 2015, computed from [9].

CSP technology	Installed capacity (MW)	Capacity under construction (MW)
PTC	3921.05[a]	866.0
LFR	162.7	56.0
ST	485.9	542.1
PDC	–	1.5

[a] Includes standalone capacity of 3740.05 MW.