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Review on Direct Steam Generation using Concentrated Solar Collectors

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ABSTRACT: This paper is mainly focused on recent research and development of the direct steam generation (DSG) technologies using concentrated solar collectors for power generation. Further, the integrated mode of operation with other conventional thermal power plants in order to increase the cost-saving and reduce the greenhouse gas emissions are discussed. The DSG mode of operation in the solar fields has several distinct advantages while compared with other non-direct steam generation modes of operation like unfired boiler and flash boiler etc. This paper focuses the operational problems and challenges encountered during the solar parabolic trough collector-based power generation with the recent and future aspects.

Keywords: Solar thermal power plant, direct steam generation, parabolic trough collectors, Parabolic dish solar collectors, thermal energy storage.

INTRODUCTION

The use of solar energy for our energy needs is a commendable option for its renewable and sustainable nature. The cost of power generation from solar is still 3 to 4 times higher than the fossil fuel based thermal power generation. The initial cost of deployment of renewable energy systems is the prime reason for its high unit cost and the need of the hour is efficient conversion technology with comparable cost. This solar energy is diluted form of energy but if a suitable concentration mechanism can increase the temperature of a thermal mass up to 1500°C.

Most of the steam Rankine power cycles can operate effectively in the range of 350 to 550°C. The concentrated solar power (CSP) is the right source candidate for the electrical power generation for its zero emission and renewable nature. The recent development in the high temperature solar receivers are reviewed by Senthil [1]. Various receiver designs are investigated to improve the overall thermal performance of the solar thermal systems.

DIRECT STEAM GENERATION USING SOLAR COLLECTORS

The major three types of DSG systems are the parabolic trough collectors, dish type concentrating collectors and central receiver power generation systems. A higher operational temperature (above 500°C) solar parabolic trough vacuum receiver was designed and parametric study was carried out by Guangjie Gong et al. [2]. An alternative cycle was modelled by Chacartegui et al. [3] for concentrating solar plant operation with CO_2 and organic Rankine cycle.

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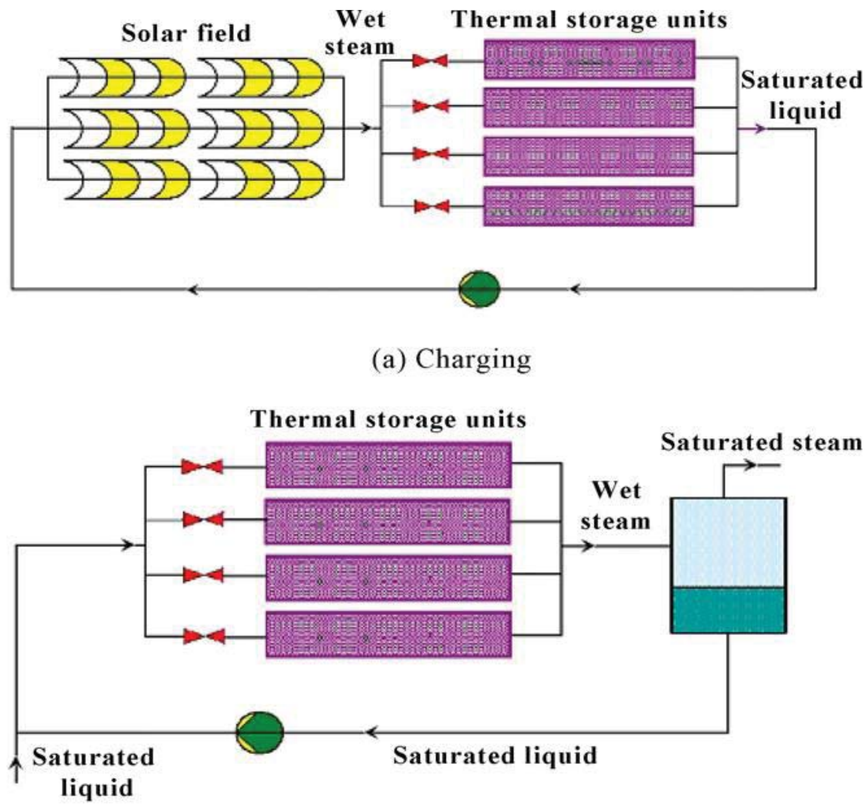

(a) Charging

(b) Discharging

FIGURE 1. Simplified control schemes during charging and discharging.

Figure 1 shows the simplified control schemes during the charging and discharging operations. The parabolic dish concentrators are operating with the concentration ratio of more than 100. The temperature distribution on the solar receiver and the various applications are discussed [5-7]. The peak temperature achieved with such collectors is up to 700 °C. A suitable smaller size solar receiver is useful to produce the direct steam in the receiver.

Santosh et al. [8] demonstrated a significant reduction of GHG emissions and primary energy use using biomass power. They stated that the further research in costs reduction and technology development is to be encouraged. Willwerth et al. [9] demonstrated the solar field has a nominal power of 19 MW_{th} driving a 5 MW_{el} turbine by superheated steam at 30 bar and 330 °C. The control strategies are to be researched further to improve the overall efficiency of the plant.

Yilmaz et al. [10] reviewed the modeling techniques of solar collectors. The optical modeling is analytical and ray-tracing. The thermal modeling are the steady and transient heat transfer analyses of single and two-phase flows. CFD models are also used to analyze the physics of parabolic trough solar collectors. The performance improvement of parabolic trough solar collectors are novel designs, passive heat transfer enhancement, and nanoparticle laden flows.

Islam et al. [11] reviewed the recent advances in concentrating solar power technologies and the scope for the direct steam generation. Supersonic injector is used in the DSG plant [12]. Niazman et al. [13] investigated the effect of graphene oxide on DSG and the observed the maximum total efficiency of 78.9% at 3.5 Suns.

Thermal energy storage (TES) is encouraged to use with the DSG for the continuous power generation. Various energy storage materials and methods are investigated in the recent years to enhance the overall productivity of the solar concentrated collector based DSG. Figure 2 shows the three sections of preheating, evaporation and superheating of feed water from the pump and to the steam turbine for the power generation. This is the concept of once-through flow of heat transfer fluid.

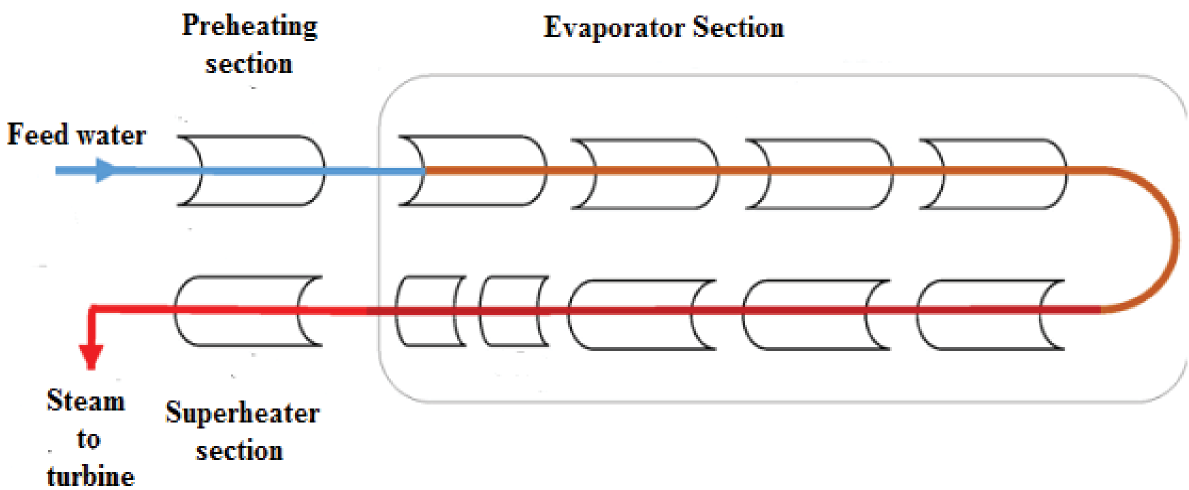

FIGURE 2. Three heating sections of PTC array

PCM storage for heating applications can improve operation efficiency from 26% to 66%, depending on specific applications. The novel materials are used in the recent years to provide the optimum performance of the solar plants. The material aspects of solar collectors are discussed by Maridurai et al.. The phase change materials are much useful for the solar thermal systems to store the bulk heat energy effectively. The effective design of solar receivers is beneficial to the DSG based solar systems. Thermal storage provides the uninterrupted power generation and this is one of the efficient ways of storing the large quantity of energy. The challenge is the control of solar thermal systems due to the non-linear dynamic heat transfer process occurring at the DSG receivers. It shows in figure 1 &2.

The TES concept using PCM is one of the recent research topics which is encouraged much to utilize the solar energy during the non-solar periods. The once-through and PCM based thermal storage are the major effective methods for the solar based power generation using DSG concept. The reheat concept is also utilized in the DSG. If the combination of once-through, reheating and PCM storage concepts are optimized, the overall energy conversion efficiency will go beyond 40%.

CONCLUSIONS

Thermal storage system combining sensible and latent heat storage is a promising option for application in DSG based power plants for the intermittent solar availability and fluctuating nature of solar energy due to climatic conditions. For near term applications in the lower power generation capacity range around 5 MW operations, the saturated steam based DSG solar plants serve as the better cost-effective option. The higher temperature and pressure operation of DSG solar thermal systems affect the materials selection for the power plant operation like piping, components, heat transfer fluids, thermal storage materials etc. The materials research for this high temperature and pressure operations will be one of the options. The steam temperature stability is an issue in the solar collector fields due to transient solar field behavior.

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