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Dry cooling of concentrating solar power (CSP) plants, an economic competitive option for the desert regions of the MENA region

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Abstract

The objective of this work is to investigate the competitiveness of dry cooling of steam power blocks of concentrating solar power (CSP) plants in comparison to wet cooling in the arid zone of the Middle East and North Africa (MENA). A case study is performed for this purpose in the Ma'an area in southern Jordan. In Ma'an water is scarce, expensive and restricted. Thus dry cooling of a power block is an attractive option. For the study purposes, a reference parabolic trough CSP power plant that is based on design of Andasol power plant in southern Spain is considered. The reference power plant has a nominal capacity of 50 MWel with 7.5 full load storage hours and is simulated with Greenius software (DLR, 2001) for both dry and wet cooling options. The reference power plant is simulated in its original location in order to validate the results using actual values of the plant. Thereafter, simulations were conducted for the power plant at the case study site with the help of high precision ground measured meteorological data provided by the DLR's enerMENA meteorological (DLR, 2012) station installed on site.

The technical simulation at the selected site predicted good economic results thanks to the site's high direct normal irradiation (DNI) values and normal ambient temperatures (around 5628 h 10–30 °C). Although dry cooling increases cost versus wet cooling, dry cooled CSP plants still a competitive option in hot arid regions with excellent solar resource such as Ma'an and can even realize lower cost than equivalent wet-cooled plants located in regions with lower solar resource. In this context, from the technical and economical point of view, the dry cooling option in Ma'an showed to be feasible.

The reference power plant produces at the selected site in Jordan with dry cooling option 180.54 GW he net annual energy yield, with 4108 full load operating hours. 13.1% annual mean overall efficiency, with a water consumption of 59,991 m^3/a, and 0.1444 €/kW h the levelized cost of electricity (LCOE). Whereas, the wet cooled reference power plant produces 201.06 GW he net annual energy yield, with 4399 full load operating hours. 14.6% annual mean overall efficiency, water consumption of 751,618 m^3/a, and 0.1258 €/kW h LCOE.

By comparing the wet cooled reference Andasol power plant in Spain with the same but dry cooled power plant in Jordan, following outputs are resulted: the overall efficiency of the dry cooled plant in Ma'an is reduced by 3.1%, the water consumption reduced by 92%. The energy yield increased by 21.8%, and the LCOE reduced by 18.8%. The results of this study prove that dry cooled CSP power plants in sites with significantly high DNI values is an attractive economic and technical option to be considered in future planning of new projects.

Keywords: Dry cooling; Concentrating solar power (CSP); Middle East and North Africa (MENA); Greenius simulation software

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1. Introduction

Solar energy technologies are the most promising renewable sources for the future world energy, photovoltaic, which is direct conversion from light energy into electricity, and concentrating solar thermal power called also concentrating solar power (CSP) are the two common technology types utilize solar energy to generate power. CSP shows attractive features to be installed in utility scale. On-grid CSP power plants with thermal storage should stabilize the grid and secure the dispatchability of power. These power plants consist mainly of the solar field and the conventional power cycle. Most matured CSP technology is parabolic trough technology, which operates in general with conventional steam Rankine cycle for power generation.

Thermodynamics rules state that wet cooling of conventional steam power cycles is advantageous over dry cooling in terms of power block efficiency since with wet cooling option the exit steam from the turbine will be cooled down faster and to a lower temperature than with dry cooling. CSP parabolic trough power plants are not an exception because they operate an identical conventional steam power cycle and operate better with wet cooling system. However, unlike the conventional fossil fuel fired power plants, which are normally located in the coastal regions, where atmospheres are generally unclear, the most suitable regions to erect new CSP plants are generally in desert regions of the earth's Sun Belt, e.g. the Middle Eastern and North African region (MENA), with high values of direct normal irradiation (DNI) but also with water as scarce and expensive commodity. Here merges the need to investigate the economy and competitiveness of deploying dry cooling option for CSP power plants in attractive regions of the MENA region.

Several studies by NREL showed that dry cooling could save more than 90% of water consumption (Turchi et al., 2010), on one hand. On the other hand, the overall performance of such a power plant is reduced under higher ambient temperatures. Such losses would be compensated entirely by higher DNI and the high efficiency when the ambient temperature is low. Hence the design of a CSP plant, especially its solar field, depends also on which cooling system is used; a bigger solar field for dry cooling than of that for wet cooling for the same power output. This results in higher investment costs for dry cooled power plants than those of wet cooled plants with the same power production capacity.

CSP power plants require huge initial investments. While any additional costs are undesired and would threaten securing project finance. In this context a trade-off between all options should be made for each specific site to know whether to use dry cooling or not. For many locations, dry cooling is the only affordable option and therefore must be considered but after its economy has been evaluated.

The main objective of this work is to evaluate the use of dry and wet cooled CSP parabolic plants in Ma'an site in Jordan as an example for the MENA region. This will be done by establishing a comparison between both options based on a reference plant design of Andasol in southern Spain. The comparison is held for the technical performance and the economics of the plant options to show that high DNI could compensate for the efficiency losses of a dry cooled plant.

2. Methodology

After selecting and assessing the case study site, the reference plant was selected and configured to have the main features of Andasol plant in southern Spain (Table 5.1). Thereafter, configurations of wet and dry cooling systems were fixed. In a following step, the reference power plant was simulated in its actual location and the simulation results have to be validated with the real power plant output to give good basis for further simulations and comparison in the case study site. To enable generating accurate simulation results, high precision ground measured meteorological data from enerMENA meteorological station in Ma'an (DLR, 2012) were obtained, analyzed and used in the simulation runs.

For the simulation runs in Ma'an, the pre-design parameters of the reference power plant are fixed to have a good comparison base for dry and wet cooling options. Subsequently, only the weather data of the sites were varied. Three major steps were followed: simulation of Andasol design in Spain as a reference, simulation of the same plant design in Ma'an region, and finally performing assessment of dry cooled plant in study location. Finally, realistic simulation results of the economic feasibility for both the dry and wet cooling options were performed for the site.

3. Case study site

The site chosen for this study is Ma'an development area near Ma'an city: 200 km south of the capital city of Amman, 9 km from the city of Ma'an and 100 km from the port city of Aqaba. The site coordinates are (N 30.17°E35.78°) and this represents an attractive location for CSP in MENA region, due to high DNI values (ca. 2693 kW h/m^2 a) DLR, 2012 and because of the expected and desired socio-economic impacts on the area.

On the study site, one enerMENA ground meteorological is mounted and has delivered reliable meteorological data since 2011. A Meteodata file was generated from these data to be used in Greenius plant simulations. Fig. 1 shows the monthly and daily distribution of average DNI values in the study site.

The figure demonstrates the annual DNI values and their daily distribution at the study area. It is obvious from the figure that the highest DNI is always around noon reaching its extreme between June and August.