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Towards the hybridization of gas-fired power plants: A case study of Algeria

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ABSTRACT

The vast solar resource available in Algeria and the high temperatures recorded in this country make the solar thermal integration of gas-fired power plants (ISCC) an attractive method to increase yield by means of solar energy. A feasibility study of potential solar thermal hybridization with parabolic trough technology was performed in 21 Algerian open cycle gas turbines and combined cycle gas turbines, which represent about 97% of electricity generation. An yield increase of 24.9 GW h/year and CO_2 emission savings of 9.91 kton/year were determined to be feasible with solar field sizes ranging from 30 to 37 loops in combined cycle centrals. In the case of open cycle gas turbines, a solar potential of 1085.7 GW h/year and CO_2 emission savings of 652.1 kton/year were recorded with solar shares in the range of 3–4%. The ISCC production model is provided herein as complementary material for future replications of this study (freely available without restrictions in R language) at http://www.github.com/EDMANSolar/AlgeriaSolar.

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1. Introduction

Algeria has one of the greatest reserves of natural gas and oil in the world, estimated at 4.51 trillion cubic meters of natural gas and 12.2 billion oil barrels [1]. In 2011, Algerian electricity generation totaled 46.25 TW h, and most of this electricity (around 97%) comes from gas-burning thermal power plants (13 GW), basically open cycle gas turbines (OCGT), 8 GW, and combined cycle gas turbines (CCGT), 5 GW. The high installed power of OCGT in Algeria is explained by the low cost of natural gas in this country and also lower cost of investment of OCGT compared to CCGT [2]. The growth in electricity generation reached over 6% between 2000 and 2010 while population growth was just 1.8% [3]. And furthermore, the increasing water demand in Algeria will supposedly increase desalination in coastal areas (the country's most densely inhabited region), which has a high energy demand in the range of 3–4 kW h/m^3 using reverse osmosis technology [4].

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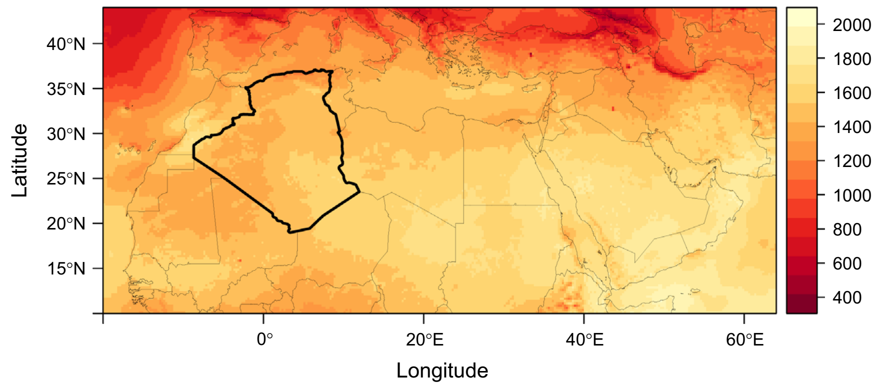

Fig. 1. Annual direct horizontal irradiation for 2013 from the SID product by the Satellite Application Facility for Climate Monitoring (CM SAF, copyright 2013 EUMETSAT) in kW h/m^2.

The electricity price was fixed to 2.2 dinar/kW h (equivalent to 0.027 $/kW h) in 2005 [5], which is one of the lowest prices in the Middle East and North Africa region (MENA). In order to meet the increasing electricity demand, 6 new 1.4 GW CCGTs will begin operating in 2015. However, Algeria's situation also presents high potential for solar energy development thanks to its solar resources, where in some areas annual sums of direct normal irradiation total over 2500 kW h/m^2, which is indeed much greater than any region of Europe (Fig. 1). During recent years, the Ministry of Energy and Mines along with the primary utility in Algeria, Sonelgaz, have been implementing a renewable energy plan with the goal of solar energy constituting 37% of the electricity generation by 2030, mainly through concentrated solar power (CSP) [6]. A feed-in-tariff law for solar energy was established in 2004 based on the solar fraction [7]. This energy plan is considering exporting a portion of its solar generation to other countries, 2 GW by 2020 and 10 GW by 2030 [8].

The high air temperatures registered in Algeria lower the efficiency of both OCGTs and CCGTs due to the volumetric machine behavior of gas turbines. During these periods high direct normal solar irradiation generally occurs, which makes solar hybridization via integrated solar combined cycle (ISCC) or open solar Brayton cycles (OSBC) very appealing alternatives to increase efficiency and yield in these plants. Thus, it is clearly not a coincidence that Algeria pioneered an installation of ISCCs with the Hassi R'Mel ISCC power plant in 2011. This power plant consists of 150 MW total and 30 MW solar. Three other ISCC projects of 400 MW each (SPPII-70 MW solar, SPIII- 80 MW solar and Hassi R'Mel II-70 MW solar) were reported in Algeria in 2013 [9].

Different studies have analyzed the performance of a single ISCC with varying steam turbine sizes and configurations, such as the Yazd ISCC [10–12] and Hassi R'Mel ISCC [6,9,13]. Antonanzas et al. [14,15] assessed the impact of converting 30 different operating CCGTs into ISCCs, with different scenarios and without enlarging the steam turbine size, on the Spanish electricity system. This study concluded that it was possible to achieve increments in overall efficiency within the range of 0.6–1% for 400 MW CCGTs with solar fields of 10-loops of LS-3 parabolic troughs. However, to date, no studies have reported on the impact of converting both OCGTs and CCGTs into ISCCs. The 97% of the Algerian electricity system is based on these technologies. This study aims to evaluate the potential of solar hybridization in Algerian OCGTs and CCGTs based on different scenarios and taking into account thermo-dynamic and economic criteria.

2. ISCC parabolic trough technology

ISCCs present some benefits when compared to regular parabolic trough CSP plants, such as the lower investment cost per MW, since many components and resources (plant staff) of an original gas fired power plant can be integrated into a hybrid plant. And furthermore, no daily startups and shutdowns are required in the turbines, and there is less variability in turbines due to weather transitories [14].

The parabolic trough with heat transfer fluid (PT-HTF) solar field providing solar heat to the Rankine cycle of the steam turbine of a CCGT is the most common ISCC technology. This is because of the development and cost reduction of the PT-HTF technology for CSP plants worldwide. The capacity of ISCC installed and under development around the world totals 4.25 GW (256 MW solar), and is divided among 8 different power plants in the USA (MNGSEC, Victorville 2, Palmdale), Italy (Archimede), Morocco (Ain Beni Mathar), Egypt (Kuraimat), Iran (Yazd) and Algeria (Hassi R'Mel ISCC) [14].

The heat transfer fluid presents some limitations in working temperatures (degrading >390 °C) and as a result, solar heat is generally used to displace latent heat of the steam turbine. Another limitation of ISCC development is water usage, which in the case of a CSP plant with wet-cooling is reported to fall within the range of 3.5 m^3/MW h, which breaks down as 95% for the cooling system and 5% for mirror cleaning and steam turbine water requirements [6]. Nevertheless, this water consumption can be reduced through dry-cooling technology, which is detrimental to yield at about 10%. Dry-cooling technology is especially recommended for desert areas, such as the region analyzed herein.

3. Algerian gas-fired power plants

A total of 29 different gas-fired power plants are connected to the Algerian electricity grid accounting for 13.3 GW divided among OCGTs, CCGTs and an ISCC. The suitability of these power plants to integrate solar energy was first evaluated by an inspection in order to determine if there was sufficient flat land available for the solar field in the surrounding area (at least 120,000 m^2 and with a slope less than 30 m). The power plants that did not meet these conditions were not given further consideration. The Hassi R'Mel ISCC was not considered since it was already using solar thermal energy. So finally, 21 gas-fired power plants were object of this study. Table 1 shows the general specifications of these power plants and average climatic conditions. The study was performed with hourly data from typical meteorological years obtained from the well known database Meteonorm 6.1.

Fig. 2 shows a topographical map of those power plants deemed suitable and non-suitable for conversion into solar hybrid power plants. Most of the power plants are located along the coast line, which presents the possibility of wet cooling.