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Peak shaving strategy through a solar combined cooling and power system in remote hot climate areas

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HIGHLIGHTS

- A solar combined cooling and power (SCCP) system is simulated in island mode.
- The case study refers to a combined cycle with solar field and absorption chillers.
- Electrical and cooling demand are matched for typical winter and summer days.
- The SCCP system has higher efficiency than a conventional pure fossil plant.
- Another advantage of the SCCP system is the reduction in fossil fuel use.

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ABSTRACT

An effective combination of district cooling with electric power production in an integrated solar combined cycle is presented and evaluated. A remote area in hot climate is assumed as location to highlight the importance of peak shaving strategy in an isolated or weakly interconnected power system. Two solutions for handling peak power demand are taken into account in the present investigation. On the one hand, the integration of a Concentrated Solar Power system (CSP) with a combined cycle power plant is considered to match peak power demand on the grid. On the other hand, the adoption of a district cooling system where cooling energy is produced by absorption chillers is proposed, instead of mechanical refrigeration, to reduce and flatten the load profile.

The case study refers to a combined cycle (CC) based on a 46 MW Siemens SGT-800 gas turbine. The CC plant is integrated with a parabolic trough collectors (PTC) solar field and double-effect steam driven absorption chillers feeding a district cooling network. The solar combined cooling and power (SCCP) system is designed to operate in "island mode" to match both electrical and cooling demand on an hourly basis, on a typical winter and summer day. A modeling procedure is applied to accurately simulate the plant operation, including off-design behavior of all plant components. During the day the solar source has the highest priority, whilst the gas turbine (GT) is operated at part-load to follow the load profile.

Electric efficiency and fuel savings for the SCCP plant are computed and compared against the ones resulting from a conventional pure fossil system based on analogous combined cycle and compression refrigeration units. Results show that a SCCP system can significantly reduce fossil fuel consumption in both summer and winter peak hours, while providing higher overall efficiency through the whole day, both in summer and winter.

1. Introduction

In the days ahead, sustainability is expected to become a fundamental element of word politics and a key factor in efforts for economic and social growth. When focusing on the field of sustainable energy systems, the need of matching electricity production to electricity demand in an environmentally-friendly manner raises different issues of major importance: (i) to reduce global warming, (ii) to replace oil for primary energy, (iii) to find alternative approaches to energy generation aiming at reducing cost and risk of conventional fossil fuels. Renewable energy is a valuable option for mitigating climate change while still satisfying energy demand. This is why deployment of renewable energy technologies has increased rapidly in recent years, not only as stand-alone power supply systems but also as integrated across the wide range of

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Nomenclature

ABS	absorption chiller
CC	combined cycle
Comp	compression chiller
COP	Coefficient of Performance
CSP	Concentrated Solar Power
DNI	direct normal irradiation, W/m^2
DSR	demand side response
ECO	economizer
EVA	evaporator
GT	gas turbine
HP	high pressure
HRSG	heat recovery steam generator
HTF	heat transfer fluid
HX	heat exchanger
Ia	incidence angle
IGV	inlet guide vanes
I_b	beam radiation, degrees
K	incident angle modifier
ISCC	integrated solar combined cycle
LHV	low heating value, J/kg
LP	low pressure
m_{fuel}	fuel mass flow rate, kg/s
P_{el}	electric power, W
P_{th}	thermal power, W
PTC	parabolic trough collector
SCCP	solar combined cooling and power (plant)
SH	superheater
ST	steam turbine
T	temperature, K
η	efficiency, %

present fossil energy plants. Hybrid (renewable and fossil) energy systems can improve the overall efficiency and provide a more reliable supply of electricity, whatever the load demand, as compared to separate use of such systems. Moreover, combination of technologies in hybrid plants may lead to higher renewable energy shares than the low levels typically found in the current energy mix. However, some issues need to be faced. Firstly, hybrid systems require not only optimal sizing to meet the load requirements [1] while minimizing investment and capital costs, but also advanced control tools to assure safe operation [2]. Secondly, to achieve commercialization and widespread use, an efficient energy management strategy needs to be implemented. In the published literature there are several contributions discussing technical, economic and environmental issues related to possible scenarios of the penetration of renewable sources for energy generation, at international, national and local levels, as reported in [3].

The present work was intended to contribute to the process of identification of new solutions for the transition from a "fossil-fuel-based" energy generation system to a smart "renewable-based" scenario. A remote area in hot climate was assumed as location. Accordingly, the opportunity to integrate solar power into an isolated or weakly interconnected power system, based on a combined cycle, and the problem of summer peaking electricity demand due to air conditioning were both addressed in this study. The resulting scenario fits well with the current situation in the Middle East countries. For example, efforts by Saudi Electricity Company SEC in the Kingdom of Saudi Arabia to meet the mounting demand during peak times are reported in [4]. In the same geographic context, an extensive review of the various gas turbine inlet cooling technology options was provided by Al-Ibrahim and Varnham [5]. Methods of increasing the energy contribution from existing gas turbine plants through inlet air cooling can make a substantial contribution to the summer peak demand for electric power which almost doubles the off-peak demand in Saudi Arabia. Another example is provided by Ameri et al. [6]. They focused on gas turbines coping with the peak electricity demand in Iran. The use of thermal energy storage for gas turbine inlet cooling was studied to increase the gas turbine peaking capacity during operation in hot weather. Similarly a study of capacity enhancement of the Chabahar (in the south of Iran) gas turbine installation using an absorption chiller was performed by Ameri and Hejazi [7].

Also, examples of hybrid systems including solar power and air conditioning are documented in literature as specific case studies. Ref. [8] assumed that the base load demand (in the state of Victoria, Australia) is supplied by conventional base load generators, with solar power generators able to supply up to 4500 MW electrical maximum in day time. The analysis demonstrates that matching the daytime demand profile with the corresponding instant solar power supply profile may help reducing peak demands and their prices. Existing experiences and realizations of PTC in solar cooling systems are summarized in [9], as well as survey of PTC potential application in feeding double effect absorption chillers. The different solar cooling technologies are discussed in [10] in view of the potential to reduce the electricity consumptions. Solar thermal with single-effect absorption system resulted in the best option. Calise [11] developed a dynamic model of a solar heating and cooling system based on the coupling of PTC with a double-stage LiBr–H_2O absorption chiller; auxiliary energy for both heating and cooling is supplied by a biomass-fired heater. System performance is computed for seven Mediterranean cities in Italy, Spain, Egypt, France, Greece and Turkey. As expected, the economic profitability is higher for the hottest climates.

Another smart use of solar energy was studied by Palenzuela et al. [12]. They evaluated different alternatives for the integration of desalination technologies in the cooling of CSP plants in the Mediterranean area, where fresh water shortage coexists with high solar radiation. Simulation results showed that the integration of a thermal vapor compression multi-effect distillation plant into a CSP plant is more competitive than each plant independently. The coupling is more efficient thermodynamically and also more economic than the decoupling, since it requires a smaller solar field for the same power and water production.

Recently, the concept of smart grid has been successfully applied to the electric power systems with the aim of integrating renewable energy sources into power system grids. A review of work done in renewable smart grid systems across the globe indicates the promising potential of such research characteristics in the future [13]. On the other hand, the great challenges posed by integration of large amounts of renewable resources to both planning and operation of modern electric infrastructures are discussed by Wang et al. [14]. Abdullah et al. [15] pointed out that the integration of renewable generation has impacts on the energy supply and service continuation of the distribution networks, because of the time varying demand and the uncertainty in power generation from renewable energy. Demand side response (DSR) models such as the one presented in [16,17] assist electricity consumers from peak to off-peak demand periods averting congestion on the electrical network. This is expected to enable consumers to be engaged in mitigating peak demands on the electricity network and make improved utilization of the electricity infrastructure. Additionally, the scheme enables commercial and industrial consumers to achieve immediate financial savings. For residential consumers