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Concentrating solar power hybrid plants – Enabling cost effective synergies

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ABSTRACT

This paper categorises different concentrating solar power (CSP) hybrid options into light, medium and strong hybrids and discusses the combination of CSP with coal, natural gas, biomass and waste materials, geothermal, and wind. The degree of hybridisation depends on the interconnection of the plant components. Light hybrids create only limited synergies, such as the joint use of a substation, and their cost reduction potential is therefore limited, while strong hybrids share major plant components, such as steam turbine and condenser, and can better match their energy output with electricity pricing.

The hybridisation options for CSP with different energy sources are plentiful ranging from feedwater heating, reheat steam, live steam to steam superheating with some options better suited for a specific energy source combination than others. The synergies created in hybrid plants can lead to cost reductions of 50%, better energy dispatchability as well as revenue maximisation.

Several CSP hybrid studies exist for coal, natural gas and biomass but these are often investigating a specific hybrid concept. This paper considers several options at a higher level and also includes geothermal and wind which is novel.

While the paper focuses on Australia the approach taken and concepts discussed are transferable to other countries.

1. Introduction

Despite an excellent solar resource and some state and federal programs for concentrating solar power (CSP) there is no commercial standalone CSP plant in operation in Australia yet. Some proposals secured significant state/federal funding, such as AU$464m for 250 MWe SolarDawn and AU$60m for 40 MWe SolarOasis projects, but neither was able to secure the remaining funding and had its support subsequently withdrawn [1,2]. Policy uncertainty and CSP's comparatively high investment compared to other renewable energy sources, such as wind and biomass, in a traditionally low wholesale cost electricity market are key reasons for the poor success rate.

Different to standalone CSP plants hybrid plants are being built in Australia with one plant already operational at Liddell, New South Wales [3], and another one under construction at Kogan Creek, Queensland [4]. Several studies investigate hybrids with gas [5,6] and even biomass [7] but none have yet been built.

CSP hybrids are well established worldwide, predominantly with natural gas [8–10] but also biomass [11], and provide lower cost benefits through the joint use of plant equipment, such as steam turbine, condenser and feedwater equipment, and better energy dispatchability as the host plant can provide electricity during times when CSP is not operating. Both aspects could help the Australian CSP industry to start grow their market share, ramping up manufacturing capabilities as well as gaining relevant project implementation experience. The wind and PV industries realised learning curve cost reductions of 15–20% when doubling cumulative deployment [12] and the CSP business could benefit similarly. At the same time plant operators and financiers would become more familiar with the variety of CSP technologies and their specific benefits. Another benefit of hybrid projects is the smaller investment, which reduces financial risk, and would particularly help newly developed CSP technologies to prove their capabilities. Due to a minimum CSP plant efficiency scale of 10–100 MWe for standalone systems such projects incur a higher financial risk over kWe scale PV systems. However, CSP add-on references exist at sizes of only 9 MWth [3].

Typically, standalone CSP plants require a direct normal irradiance (DNI) levels >20 MJ/m^2/day but the lower specific investment

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of hybrid systems allows the implementation in lower DNI areas which are often closer to load centres. The first CSP–biomass plant in Spain is located in 18 MJ/m^2/day DNI area [13] and other studies consider regions with even lower DNI levels of 17 MJ/m^2/day [14].

Natural gas, biomass and waste materials as well as geothermal are obvious energy sources to hybridise with CSP as such plants can share Rankine cycle equipment but also the integration of wind has benefits in terms of joint use of plant infrastructure and energy dispatchability.

While CSP hybrids are being discussed broadly in academia and industry with several studies on different integration options for CSP with a specific fuel, this paper categorises hybrid plants and discusses not only one energy source but several.

2. Methods

The technical and economic information provided in this paper derive from the literature and own modelling work using Thermoflex version 23.0. The software is widely used in academia and industry to model actual gas, biomass, waste, coal, geothermal and CSP plants.

The maps provided are based on publically available information which is combined using a commercial imaging software. References to the different energy sources, DNI, and transmission infrastructure are provided in each relevant section. Sites with a DNI >18 MJ/m^2/day are considered suitable for CSP hybrids as commercial plants already operate in such DNI areas [13].

3. Hybrid categories

With a variety of possible CSP hybridisation options it is sensible to categorize these to better assess the degree of dependence between CSP and the other power generation component. The following three categories are suggested to do this.

3.1. Light hybrid synergies

Light CSP hybrids only share minimal plant infrastructure and the operation of the different assets does not depend on each other, such as CSP and a wind farm jointly using the switchyard and substation. This results in only minimal cost savings unless both plants can share the cost for building new transmission infrastructure, which would be a major benefit as transmission lines are capital intensive.

Despite the minimal interaction of both generation assets one plant could use certain equipment from the other to enhance its energy dispatchability/limit curtailment if this equipment is not being used at its maximum capacity at this point of time. One example would be a wind farm topping up the thermal storage of a CSP plant in winter to store some of its electricity via electric heaters in molten salt for dispatch at higher electricity prices at a different time of the day.

3.2. Medium hybrid synergies

Medium CSP hybrids are physically connected with each other and share major equipment, such as the steam turbine or condenser. However, the CSP component requires the operation of the typically much larger host plant while the host plant can operate without the CSP component. Currently, this is the dominant form of CSP hybrids where the CSP plant provides feedwater heating [3], cold reheat steam [4], or a saturated/superheated steam boost [8,9,15]. These concepts exist for CSP with coal and natural gas.

Due to the joint use of capital intensive plant infrastructure cost reductions can be significant but the solar share in these concepts is typically below 10% of the installed plant capacity.

3.3. Strong hybrid synergies

Strong CSP hybrid plants are physically connected with each other, share major equipment and have a significantly higher solar share, >30%, compared to medium CSP hybrids. CSP plants using another fuel to further superheat its steam fall in this category, such as 100 MWe SHAMS One using natural gas [16]and 22.5 MWe Termosolar Borges using biomass [13]. Alternatively the CSP component can be used to raise the steam parameters of low temperature renewable energy sources, such as geothermal plants [17]. The external superheating concept increases plant efficiency and hence lowers cost. Strong hybrids also include plants where CSP and the other energy source provide similar quantities of high temperature/pressure steam parameters to the joint turbine, e.g. 30 MWe CSP hybrid study for Griffith, Australia [18].

Strong hybrids can reduce specific plant investment significantly while enabling solar shares of 30–90%.

4. Hybridisation options

Several hybridisation options exist to integrate CSP into the Rankine cycle of another power plant. They include feedwater heating, reheat steam and high pressure/temperature live steam, see Fig. 1, and the most suitable CSP technologies for these options with biomass, waste, natural gas and coal have been assessed recently [19]. All three options have been implemented in reference plants worldwide, e.g. Liddell [3] and Kogan Creek in Australia [4], Martin Next Generation in the USA [8] and Archimede in Italy [15].

Using CSP to externally superheat low temperature steam is another option which has not been realised yet, but the concept is discussed in more detail in Section 4.4.

4.1. CSP–coal

Several studies investigate the different CSP integration options with utility scale coal fired power stations [20–22] and from a technical and commercial perspective they are all sensible with positive results in terms of CSP cost reductions and conversion efficiencies, e.g. specific investment of AU$2.4/MWe for Kogan Creek solar boost [4]. However, when proposing CSP retrofits to coal fired power plants other criteria, such as age and remaining lifetime of the power station, have to be considered carefully to assess the real greenhouse gas abatement potential and avoid "greenwashing". With coal fired power stations having a design lifetime of circa 40 years and CSP plants requiring up to 20 years to amortise, coal plants older than 10–15 years should not be retrofitted as extending its operation only for a short period of time can offset the avoided greenhouse gas emissions from the CSP add-on due to the typically small solar contribution, well below 10% of the plant capacity.

The recently commissioned 9.3 MWth CSP feedwater boost at the 2 GW Liddell power station is an interesting example as it reduces greenhouse gas emissions by approximately 5000 t/a [3], which is equivalent to only 2.8 h of full-load operation of the coal station with its carbon intensity of 892 kg/MWh or 0.064% of the stations 2011–12 annual emissions from 8764 GWh of electricity generated [23]. There is no doubt modern power stations exist, typically supercritical, where a solar boost makes economic and environmental sense, such as 44 MWe solar boost to 750 MWe Kogan Creek power station [4], as these latest generation plants, Kogan Creek was commissioned in 2007, are most likely to operate for the next 25–30 years. However, other projects might add a small renewable energy component to an older unit to justify operation beyond the initial design lifetime. The recent CSP feedwater booster at the Liddell power station could be such a case as