SolarPACES 2012 Conference Report

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This report has been written for the Australian Solar Institute (ASI) by José Zapata as part of a travel grant to attend the SolarPACES 2012 conference in Marrakech, Morocco. The author is a a PhD candidate at the Australian National University, working the modelling and control of direct steam generation using cavity receivers and paraboloidal dishes. As a consequence, this report focuses the topic of direct steam generation technology and the insights gained on this field from the conference. The author wishes to acknowledge the support provided by the ASI for this trip, without which, attendance to and benefit from this conference would have not been possible.

Introduction

Concentrating solar thermal (CST) systems are gaining momentum as a viable source of renewable energy, thanks to a renewed interest in research and development over the past 5 years. This resurgence of interest in CST systems has not been hindered by a continuous drop in price of Photovoltaic systems thanks to the recent deployment of thermal energy storage in commercial scale plants in Spain.

The benefit of thermal energy storage (TES) is the ability to produce store excess energy collected during the day and release it at a later time, usually after sunset, extending the operational range of the plant. Furthermore, it has highlighted the key advantage of CST over other renewable energy solutions, which is the ability to decouple the injection of power to the grid from the renewable energy source (sun, wind, etc.). This ability to inject power to the grid at times of high demand, independent of the time of day is termed 'dispatchability'.

Efforts to reduce the overall costs of CST plants continue, in a drive to be competitive against conventional power generation, in particular fossil fuel plants. These efforts include the increase in thermal efficiency of the plant and the reduction of components on the overall plant. One of the technologies under consideration for the near future is direct steam generation.

Direct steam generation (DSG) consists of using water as a heat transfer fluid at the receiver of a CST plant. Steam can be fed directly from the collector field to a steam power block, removing the need for synthetic oils and costly heat exchangers in large scale power plants, and thus reduce the Levelised Cost of Energy (LCOE) of the system. In addition, steam is cheap, abundant and non-toxic in comparison to synthetic oil and it can be heated to higher temperatures than synthetic oil and molten salts, which provides the possibility to employ higher temperature/efficiency steam cycles and the possibility to be employed in conventional power cycles through hybridisation.

DSG plants face challenges, such as the difficulty of regulating steam temperature at the receiver(s) output(s) under variable weather conditions. Current research efforts are focused on modelling, characterisation and control of direct steam generation and alternative means to use the steam in such a way that it is less susceptible to variation in solar radiation (e.g. hybridisation and storage).

This report provides an overview of the main findings presented by the international community on direct steam generation at the SolarPACES conference. The most important role of direct steam generation in the near future is the production of steam for hybridised plants. It is a role that can be fulfilled with technology readily available, and that can conduce to improved solar-thermal systems, reduced energy costs and lower carbon emissions.

Insights from the SolarPACES 2012 conference on DSG

Technical contributions to the SolarPACES 2012 conference on DSG from industry, research centres and academia can be grouped into the following themes:

- Hybridisation
- Thermal energy storage
- Characterisation and measurement
- Modelling and Control
- Operational Experience

These themes reflect the ongoing effort of the SolarPACES community, on DSG and other technologies (e.g. molten salt plants, solar fuel projects) to improve the dispatchability, reliability and cost effectiveness of CST plants.

Broader contributions to the conference address policy, finance, insurance and risk minimisation of CST projects around the world are only briefly mentioned in this report.

Technical contributions

Hybridisation and storage contributions are concerned with the proposal and evaluation of plant configurations that combine DSG collectors with conventional power blocks or suitable thermal storage for standalone plants. Hybrid plants with DSG range from small solar contributions for a coal and natural gas fired power station to plants that are predominantly solar thermal that contain a small gas fired back up.

Thermal energy storage (TES) is the research into the incorporation and development of storage technologies for storing the thermal energy of steam in DSG plants. The aim of these efforts is to combine the dispatchability and reliability of storage with the higher efficiencies and lower costs of direct steam generation plants.

Characterisation, modelling and control efforts presented at the conference relate to research projects that study the physical behaviour and properties of DSG concentrators and receivers in order to improve their design and operation. These contributions are aimed at improving the performance and lowering the cost of DSG plants, in accordance with the increase in use due to hybridisation and storage possibilities.

Operational experience contributions report the progress of recently built plants that use DSG technology. These contributions are crucial to gauge the progress and maturity of CST technologies, as large scale prototypes and near-commercial scale prototypes offer comparable costs and performances of commercial scale CST plants.

Hybridisation

Although CST DSG power plants exist (e.g. Abengoa PS-10 and PS-20 plants) and are being constructed (e.g. Brightsource Ivanpah 392MWe plant) that are directly connected to the grid, there is significant interest in the potential for DSG technology in hybrid power plants.

A report by Siros *et al.* [1] points out that CST plants can compete with Photovoltaic (PV) systems on value (dispatchability) and cost (lower LCOE) by adding solar boosting and fuel saving capabilities to coal fired and natural gas power stations. This report takes a 1GW supercritical coal fired power station as a basis to identify potential applications for DSG collectors within its power cycle.

Solar boosting options are those where the coal fired power block is sized taking the solar field into consideration. The resulting system is cheaper than a coal only system of the equivalent power output. Fuel saving options are those where the a portion of the energy obtained by burning fuel is replaced by heat obtained from solar thermal collectors when possible, without changing the electrical power output of the plant. Both options lower the amount of fuel burned per unit of electricity produced, thus decreasing emissions, fuel costs and offer access to energy credits.

In Siros *et al.* 6 options are identified and classified as solar boosting or fuel reduction. Furthermore, DSG technologies (e.g. Linear Fresnel reflectors and central towers with steam generation) are proposed as as solution for all options. Finally, the proposed options are ranked by economic potential and technical merit. The best option is a solar boosting solution where low quality steam is obtained from solar collectors. This can be accomplished with inexpensive and mature technology (e.g. Linear Fresnel reflectors). Options where high quality steam is required are ranked lower, as more expensive and less mature technologies (DSG point focus systems) are required.

These findings summarise the key insight for DSG hybridisation. Increasing the reliability and reducing the cost of high temperature DSG systems combined with identifying the best mix of solar thermal and fossil fuel within plant designs are the main aspects that will influence the success of future solar thermal hybrid plants.

Other examples of solar/fossil hybridisation plants have been proposed at the conference. Peterseim *et al.*, proposed a small fossil fuel boiler to boost a mostly solar thermal power plant [2] and an integrated solar combined cycle, where central towers are used to boost the performance of a conventional coal fired power plant [3].

The concept of hybridisation is extended to include other energy sources. In particular, the integration of biomass/waste furnaces is proposed by Snidvongs [4], Peterseim *et al.* [5] and Servert *et al.* [6].

Servert *et al.* have presented a project called Hi-Biosoleo, a plant that combines solar thermal power from DSG and thermal oil collectors, wind, biomass and a natural gas burner backup. The aim of this project is to produce electricity mostly from renewable energy sources 24 hours a day, and to seamlessly switch between sources, thereby extending further the concept and potential for solar thermal hybridisation.

Thermal Energy Storage

Thermal Energy Storage (TES) is a key advantage for the long term competitiveness of CSP plants in a renewable energy market. Thermal energy storage reduces or in some cases eliminates the effect of varying solar radiation on the ability of a plant to dispatch power to the grid.

Molten salt technology is currently leading the trend in TES integration into CSP plants, due to its high heat capacity and relatively low cost. Limitations exist to integrate molten salt storage to a DSG plant. Molten salt storage absorbs and releases heat by sensible (i.e. with temperature change) heat transfer only, whereas the transition between water and steam occurs as latent (i.e at constant temperature) heat transfer. This incompatibility results in reduced energy efficiency in the system.

Efforts presented at the conference to improve the performance of molten salt storage for DSG systems include: a proposal to use molten salt at its freezing point for the latent heat transfer and sands for the sensible heat transfer [7]; diverting a portion of the steam from the collectors directly to the power block, bypassing the storage for certain operating conditions [8]; the usage of 3 tanks instead of 2 tanks for commercial scale TES (e.g. Gemasolar) where the additional tank is used is employed specifically for the latent heat portion of the heat exchange [9].

A potential way to overcome the limitations of molten salt storage, is the use of a Phase Change Material (PCM) in the storage tank. Unlike molten salt, PCMs use latent heat exchange to absorb or release energy and are therefore better matched to interact with boiling water. As a result, the heat conveyed from the collector field by steam is stored more efficiently in the storage tank and also extracted more efficiently than current molten salt technology to the power block.

At the SolarPACES conference, research efforts on PCM range from new materials, such as $Mg_{49}Zn_{51}$ being studied for high performance steam turbines [10],, numerical evaluations of the performance and behaviour of DSG plants with PCM storage [11, 12], and the design and testing of storage device prototypes that include PCM at their core [13].

The ongoing activities to progress storage show that despite the increased cost and complexity of adding storage to DSG plants, the potential improvements in dispatchability and the increased regulation of power output are worth the effort.

Characterisation and measurement

Two-phase flow (e.g. the transition from water to steam) is a complex physical phenomena, which is still actively under research due to the use of water as a working fluid for fossil, nuclear and CST power plants. The measurement and characterisation of physical processes involved in DSG plants contribute to a deeper understanding of two-phase flow phenomena and how it occurs in solar-thermal receivers.

Articles in this area are predominantly technical, and examples range from detailed thermal analyses of receiver-concentrator interaction [14], to two-phase flow phenomena inside the receiver tubes [15], and the influence of the optical characteristics of a concentrator in the heat transfer process occurring in the receiver [16].

Modelling and control

The operation of a CST plant influences its LCOE by determining the number of hours in a year a plant can operate and produce revenue. In particular for DSG plants, the control and regulation of steam generation in the collector field/receiver is challenging. Advanced modelling and control techniques are essential to operate DSG systems and conference submissions on this topic have increased in recent years.

In this area, research efforts focus on the dynamic modelling of the steam process in the receiver [17], the influence of the dynamic behaviour of the receiver in the operation of the plant [18] and proposals for advanced control strategies for DSG systems [19].

Characterisation, measurement, modelling and control contributions at the SolarPACES conference have been submited for other technologies, and pursue the same objective of improving the behaviour and reduce the operation costs of CST plants.

Operational Experience

Reports on the lessons learned from pre-commercial scale plants have been presented by Novatec Solar and eSolar.

Novatec Solar reported both on the operational experience of a solar augmentation loop installed at the Liddell, NSW coal fired power station [20], and their Puerto Errado, Spain 30MWe DSG loop [21]. In both reports Novatec demonstrate success and confidence in the operation of their plants, which indicates the maturity of DSG using Compact Linear Fresnel Reflectors (CLFR) technology for both hybrid and standalone systems.

The report by eSolar [22] describes their efforts to operate their 5MWe full scale prototype of multiple tower/heliostat fields. The successful operation of their plant relies on advanced control system that has been developed in-house, to control the heliostat tracking and the boiling process at their DSG receiver.

Policy, financing and development contributions

A study by Romero *et al.* [23] reports on challenges and barriers for the scale up of CST plants and programs in developing countries around the world.

The report identifies techno-economic barriers such as higher investment risks than wind or PV due to the large upfront costs and maturity level of CST technology. Also cited as barriers are lower capacity factors and higher electricity prices than fossil fuel power plants.

The report also identifies market barriers in developing countries such as competitiveness in the energy sector (monopolies, subsidies to fossil fuels), lack of infrastructure and financing instruments, lack of institutional strength (regulatory, policing and transparency in government authorities), political instability and lack of local technical and management expertise.

These factors do not affect all developing countries in the same measure and a case by case quantitative evaluation of countries in Africa, South America and China is presented in the report.

Middle East and North African (MENA) countries can overcome in part some of these challenges by seeking out partnerships with Europe. Caldés *et al*[24] review the opportunities of European Union(EU) legislation opens for cooperation with MENA countries to achieve the Europe wide renewable energy consumption targets fro 2020. This report highlights very similar challenges and barriers than Romero *et al.*, and addresses how they can be addressed by the European regulatory framework.

Developed countries such as Australia, are also evaluating the potential for greater penetration of CSP in their energy markets [25]. Developed countries with solar energy resources face the same techno-economic barriers than developing countries but market barriers are significantly reduced, which increases the chances of success for CSP plant scale up in developed countries.

Development of concentrating solar thermal power in Australia

Challenges

Australia's main challenges in the development of CST power are techno-economic, due to the maturity of local and foreign CST technology. Lack of maturity poses:

- A higher technical risk than conventional power technologies due to unsolved challenges in plant operation and integration to the electricity market.
- A higher financial risk than other renewable power technologies, due to the lack of commercial scale plants and prototypes that identify the financing/lending risk to banks.
- Reduced revenue from CST projects, as not all the potential for cost reduction has been attained for the technology.

To address these challenges, Australia needs to increase the scale of prototypes, demonstration plants and near-commercial installations, to sizes between 5MWe and 30MWe. This includes the equivalent contribution that solar-thermal collectors can provide to conventional power plants through hybridisation.

Larger scale, demonstration and near-commercial plants will reduce both technical and financial risks of CST plants. Developers can increase their technical expertise on the operation of these plants and identify potential problems in commercial scale project before their construction. This is closely linked with the opportunities that Australia has for the development of CST technology.

Opportunities

The two salient themes of the SolarPACES conference are hybridisation and storage. Plants with storage offer the advantage of dispatchable power and thus the ability to increase the plant revenue, which is advantageous for any country with an energy market with variable prices and financial incentives, including Australia.

Hybridisation is an attractive possibility for Australia. In comparison with standalone CST plants, hybridisation schemes face reduced technical and financial risks as the conventional portion of the plant is tried and tested technology and the plant can fall back to operating solely with fossil fuel.

Hybridisation also benefits the CST industry by providing opportunities to scale up their prototypes and produce near-commercial scale systems. As mentioned in the previous section, the gain of technical expertise in the construction and operation of these prototypes is tremendously valuable. Near-commercial scale prototypes such as Gemasolar molten salt tower and Novatec Puerto Errado are examples of this. Their accumulated technical expertise on the construction and operation of their plants puts them as clear leaders in the market and their technologies to be mature and reliable.

In comparison to other developing countries with high solar resources, Australia possesses very good infrastructure, a stable and transparent government and economic incentives for the development of renewable energy. This puts Australia in an advantageous position for the development of CST, comparable or even greater to the United States and Spain and this should be used to attract foreign investment in research, development and commercialisation.

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