Vast Solar 1U Validation and Performance Modelling for 1.2MW$_{th}$ Solar Array with High Temperature Receiver and Integrated Thermal Storage

Dissemination Report: Heliostat Field and High Temperature Receiver Development

Figure 1: Vast Solar 1U Heliostat Field, NSW, Australia

July 2014

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Introduction

The Australian Solar Institute (now incorporated into, and referred henceforth to, as ARENA) invests to expand solar thermal and photovoltaic research capacity with a view to restoring and maintaining Australia's position at the forefront of solar energy development and research.

As part of ARENA's competitive funding Round 3, funding was provided towards the Vast Solar Project titled 'Validation of performance modelling for a 1.2MWth solar array with High Temperature Receiver and Integrated Thermal Storage'.

The Project supported ARENA's high level goals of:

- advancing innovation in solar technologies in Australia;
- driving research capable of improving the efficiency and cost effectiveness of solar technologies;
- retaining local, and attracting international expertise in solar energy research; and
- establishing Australia as a key player in the development of solar energy technologies.

About Vast Solar

Vast Solar is an Australian company formed to deliver competitively priced solar thermal power generation technology capable of competing with traditional (fossil fuel) and wind power.

Vast Solar uses central receiver (sometimes referred to as heliostat-tower, or 'power tower') technology, and has developed designs that achieve both high efficiency in energy collection and low cost solar field design and plant deployment.

Vast Solar's core objective is to demonstrate that the Vast Solar CST system design enables high temperature and high efficiency at a low cost, and in particular that innovative engineering and construction methods can deliver significant cost reductions as compared with traditional CST plant design as deployed in other countries.

Overview – Key Drivers of Economic Performance

Economic performance of concentrating solar thermal energy projects depends on 4 key factors:

- Capital cost
- Efficiency of the concentrating solar energy capture system
- Efficiency of the thermal energy storage system
- Operating and maintenance cost.

Vast Solar's innovations address each of these economic drivers, delivering a CST system with:

- a cost structure significantly lower than any competitor system currently available globally,
- capacity to operate at high temperatures (~550C) for optimal thermal energy storage and steam turbine efficiencies.

Project Overview

Central receiver (power tower) concentrating solar thermal power plants are demonstrating significant scope for achieving breakthrough reductions in the Levelised Cost of Electricity (LCOE) and dependable supply (thermal storage).

Various design strategies are being trialed in the US, Europe and elsewhere. Recently completed central receiver plants in the US (Ivanpah, Crescent Dunes) have provided benchmarks for massive plants of 'monolithic' CSP central receiver design.

Vast Solar has developed unique technical innovations in the design of high efficiency, low cost components for solar thermal central receiver power plants with integrated thermal energy storage.

Prior to this Project, individual components of the Vast Solar system had been tested and a small prototype module comprising 50 heliostats, with a central receiver operating a water based cooling system, had been operated as an integrated system over an 18 month period at a location at Marulen, New South Wales.

This prototype module provided significant data and evidence of component performance and durability in a wide range of climatic conditions across all four seasons, with ambient temperatures ranging from -8C to 42C and wind-strengths to 100km/h.

With the benefit of testing and proving from the Marulen prototype field, Vast Solar secured further private investment to develop a 200 heliostat module at a new and larger project site in Jemalong, Central Western New South Wales. This 200 heliostat field deployed an enhanced thermal energy receiver design, also (as with the Marulen field) employing a water-based cooling cycle.

This '200H' module was designed as the initial stage of a full-scale module of Vast Solar's system design, in which 700 heliostats are deployed with a 30m central tower on which is mounted a thermal energy receiver using Vast Solar's proprietary heat transfer cycle.

ARENA's Round 3 program was focused on CSP technologies, and specifically on CSP innovation capable of demonstrating pathways to significant reductions in LCOE and the benefits of higher operating temperatures.

Vast Solar System Design

CST power generation uses the sun's thermal energy. Mirror arrays capture solar energy as heat, and the heat is stored and then released as needed to generate steam to drive a traditional turbine for electricity generation, or for industrial processes such as meat processing, brewing, or minerals processing.

In December 2011, Vast Solar completed Phase 1 of our CST demonstration facility in Jemalong, in regional NSW. Phase 1 consisted of 200 heliostats, a thermal receiver mounted on a tower, a simple heat exchanger (boiler) and energy storage tank. This demonstration system enabled Vast Solar to refine the technology, establish basic manufacturing processes for on-site production of mirrors, and demonstrate system operation for steam generation.

From January - December 2012, with financial support from ARENA and private investors in Australia and Europe, the Phase 1 demonstration solar array was expanded to include a further 500 heliostats to its full single module size (700 heliostats).

Following completion of Phase 2 and commissioning of the complete demonstration module, a further range of tests and trials have been undertaken and are ongoing, to gather data to validate the performance of the system and to inform further refinement of components, communications and control systems.

The next planned phase of Vast Solar's technology commercialisation program – Phase 3 – has commenced construction. This 6MWth Pilot Project incorporates a turbine, thermal storage and grid connection. It applies the learnings, design enhancements and knowhow developed through the 1.2MWth Validation Project.

Scope of This Project

The scope of this Project was to expand the existing Vast Solar 200H facility to full operating module size, to:

- test all components in an integrated operational plant,
- gather empirical data to validate modelling of optical and thermal efficiencies,
- investigate the design of a higher temperature receiver and novel heat transfer fluid system, and
- gather data relevant to characterisation and design of thermal energy storage.

Scope - Continued

Objectives of the '1U Module' (1.2MWth Validation) Testing Program

The primary objective of the Project was to gather empirical data on the performance of Vast Solar's low cost solar array module and high temperature receiver, and their implications for design and potential efficiency of thermal energy storage.

The primary method for this to be achieved was through quantification of the energy that could be delivered to the heat transfer fluid from the Vast Solar heliostat field, under known conditions. In particular it was desired to validate Vast Solar's Field Optical Efficiency and Receiver models, and to strengthen the accuracy of estimates applied in those models of the energy that misses the receiver (spillage).

The data collected has been used to:

- Develop and enhance plant controls
- Refine targeting accuracy and focal accuracy of heliostats
- Enhance receiver design to achieve an optimal balance of capital cost, ease of maintenance and replacement, and energy capture
- Refine plant economic modelling
- Verify calculations/simulations used for energy modelling of the system
- Support efforts to secure funding for further investment in Vast Solar's commercialisation program, to enable progressive scale up demonstration of the Vast Solar CSP technology.

As part of this Project, investigations were undertaken to:

i. Validate the viability and durability of the low cost heliostat array
ii. Validate the performance of the low cost, high temperature receiver
iii. Refine modelling and projections for, and methods for management of, thermal energy storage.

Major Project Phases

The major phases of the Project included:

- Construction and deployment of 500 additional heliostats to complete the solar array module to full scale (700 heliostats)
- Development of design, and refinement of materials selection for, a higher temperature receiver, capable of operating at 565°C, (particularly to address risks of thermal fatigue, without materially increasing receiver cost)
- Determine operational requirements (freeze front propagation) for the selected heat transfer fluid
- Operate the facility in a variety of conditions and in a variety of operating scenarios to gather performance data.

Conclusion

Vast Solar has developed unique technical innovations in the design of high efficiency, low cost components for solar thermal central receiver power plants with integrated thermal energy storage.

This Project tested components individually and as an integrated system at full, single module scale, and validated performance and cost modelling which has confirmed the potential for Vast Solar's CSP system to deliver LCOE competitive with traditional power generation and wind power systems, with the added benefit of thermal energy storage.

Vast Solar extended the pre-existing 200 heliostat array to include an additional 500 heliostats. A High Temperature Receiver was developed suitable for operation at 565°C.

The Project allowed Vast Solar to operate the 1.2MWth '1U' module, over a 24 month period. This operation has allowed the collection of data on system performance that has been used to refine plant controls, refine targeting accuracy and focal accuracy of heliostats, and to enhance receiver design to achieve an optimal balance of capital cost, ease of maintenance and replacement, and energy capture, refine economic modelling and optimise model configuration.

Importantly, it has provided data that has supported continued development and commercialisation of CST technology that can break the $100/MWh LCOE barrier.

The work completed as part of the Project has proven Vast Solar's CSP system. The experience from this Project is now being utilised in the design and construction of Vast Solar's $6MW_{th}$ Pilot project, also partly funded by ARENA. This Pilot project will also include a $1.1MW_e$ steam turbine and a 2 tank thermal storage system with 3 hours of storage