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ARENA

Novel Concepts for Low Cost Small Heliostats in Remote Installations Project Results and lessons learnt

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Executive Summary

The Project set out to investigate a range of concepts for reducing heliostat costs, with a focus on remote Australian environments. The technologies of interest were:

- A cost model for heliostats that incorporates cost associated with heliostat installations in remote locations
- A version of the CSIRO heliostat that was optimised for automotive manufacturing methods and minimum installation labour to bring down the cost
- A small heliostat concept using Rioglass Solar sandwich panel facets
- A novel direct drive linear actuator that has zero wear
- A novel system of cameras that can calibrate and control small heliostats that are up to 1.6km away, and could theoretically measure the entire heliostat field at the same time.
- Improvements to heliostat actuators, electronics and foundation designs to reduce capital costs

By working with automotive component manufacturer Diver Consolidated Industries (DCI), CSIRO was able to design and cost an automated assembly line for the version 3 CSIRO heliostat, showing that economies of scale could reduce the cost of the version 3 heliostat by 50-60% when compared to the cost of small volumes of heliostats deployed in research facilities like the CSIRO Energy Centre in Newcastle.

Using this information, CSIRO and DCI worked to develop the CSIRO version 4 design which reduces the cost of the materials and manufacturing by a further 25%. CSIRO has also been able to improve installation time, electronics and wiring design, and actuator performance. The resulting heliostat will be a step change in competitiveness for the CSIRO heliostat technology.

CSIRO has shown that the techniques it has developed for support and actuation of the CSIRO heliostat are adaptable to other commercially available heliostat components, in this case CSIRO designed and tested a heliostat that uses mirror panels produced by Rioglass Solar, the same type used in the Khi Solar One Project in South Africa, and the Cerro Dominador Project in Chile.

CSIRO has developed and proven a new type of linear actuator that has one moving part and no wear by using magnetic fields to extend and retract. Due to material and manufacture limitations, the precision of the actuator is not sufficient for the control of a heliostat, however it could have other applications such as solar photovoltaic tracking.

CSIRO has developed a novel heliostat calibration system that will enable small heliostats to be used for commercial power station sized heliostat fields, unlocking the higher optical efficiency and cost reduction available from small heliostats. This system can calibrate multiple heliostats at once, which would speed up commissioning time for commercial solar thermal power stations with heliostats of any size, bringing them online faster.

Project Overview

Project summary

The Novel Concepts for Low Cost Small Heliostats in Remote Installations Project set out to prove a set of novel concepts that could enable small heliostats to become competitive with, or even lower cost than, large heliostat designs. These were:

- A cost model for heliostats that incorporates cost associated with heliostat installations in remote locations
- A version of the CSIRO heliostat that was optimised for automotive manufacturing methods and minimum installation labour to bring down the cost
- A small heliostat concept using Rioglass Solar sandwich panel facets
- A novel direct drive linear actuator that has zero wear based on direct drive technology
- A novel system of cameras that can calibrate and control small heliostats that are up to 1.6km away, and could theoretically measure the entire heliostat field at the same time.
- Improvements to heliostat actuators, electronics and foundation designs to reduce capital costs

Project scope

At the outset of this project, CSIRO had developed significant capability in building heliostats for high temperature solar thermal research. However the goals were technical and cost was not as important.

This project set out to develop heliostat technologies that would lower heliostat capital and ongoing costs, and remove roadblocks to scalability, enabling low cost solar thermal power plants in optimal sites in Australia.

Smaller heliostats are theoretically able to use less material, and deliver more energy to the receiver, when compared to bigger heliostat. However, the number of heliostats required increases. Therefore, the challenge is to design a small heliostat with actuation, control, and foundations, at a low enough cost, and fast installation and commissioning steps, to compete with, then hopefully become cheaper than, large heliostats which can be each up to $180m^2$ each.

A multidisciplinary team from CSIRO Energy, CSIRO Manufacturing and Data61 worked together to explore completely new ideas for actuators and commissioning/calibration systems. CSIRO partnered with Diver Consolidated Industries (DCI), an automotive component supplier, to improve the CSIRO heliostat design for low cost manufacture and assembly. CSIRO also partnered with Rioglass Solar, an experienced solar thermal component supplier, to develop a version of the CSIRO heliostat that could interface with Rioglass Solar’s proven facet design.

Outcomes

A full cost model was built for the CSIRO 5.06m2 version 3 heliostat for a 20MW and 100MW project size. The results showed that although the economies of scale helped bring the price down, component manufacture and logistics costs, foundation costs and electronics costs needed to be targeted. Through collaboration with DCI, the CSIRO version 4 heliostat was improved to achieve a further 25% reduction in component costs against the high volume costs for version 3.

A heliostat with two Rioglass Solar facets was designed, the first multi-facet heliostat designed by CSIRO. A prototype heliostat was built and tested in the Newcastle heliostat field.

The direct drive linear actuator concept was proven, however it was not practical to achieve a control resolution good enough for the CSIRO heliostat. The application of the concept to other sectors is being investigated.

The camera array concept has been demonstrated through a prototype camera array tested in the heliostat fields at the CSIRO Energy Centre in Newcastle. A simulation tool to allow the design of a pilot scale or commercial system has been developed and validated. This technology will enable small heliostats to be used for large tower systems where heliostats can be over 1.5km from the tower. Ultimately, it could enable closed loop control of heliostats, which could reduce controller costs and improve control significantly.

In order to get the best performance from the new CSIRO heliostat design, the Heliostat Actuators and Actuator Controllers have been significantly improved to achieve the desired optical performance, improve reliability and lower costs. This is an important step towards the further commercialisation of the CSIRO heliostat technology.

Transferability

Many of the technologies developed can also be applied to heliostats of any size, for example the Camera array concept could improve calibration and commissioning time for large heliostats, by allowing many heliostats to be calibrated at once.

CSIRO is a contributor to SolarPACES, through task meetings and conferences. CSIRO has presented the camera array concept in this forum and will present further findings in future conferences.

Publications

M. Collins, D. Potter, and A. Burton, “Design and simulation of a sensor for heliostat field closed loop control,” *AIP Conf. Proc.*, vol. 1850, no. 30009, 2017 (https://aip.scitation.org/doi/abs/10.1063/1.4984352)

Intellectual Property: Patents / Licences

The version 4 heliostat technology is being licensed to HeliostatSA, a joint venture for the manufacture of heliostats and PV trackers emerging from the declining automotive component manufacturing sector in South Australia.

The camera array concept and its use for closed loop control has been patented

Improved Heliostat calibration and control 1	AU2013902542
Improved Heliostat calibration and control 2	AU2014900365

Awards

None

Conclusion and next steps

The improvements to CSIRO heliostat designs will enable continued improvement of CSIRO's heliostats deployed in research facilities in Cyprus, Adelaide and Newcastle. These systems are used for academic research and development of next generation receivers.

This project is an important step towards the further commercialisation of the CSIRO heliostat technology. CSIRO and technology licensee Heliostat SA are planning joint activity to test the version 4 heliostat and improved actuation system thoroughly, and refine the improvements to allow HeliostatSA to offer this heliostat design to new project proposals. This process will pass on the associated cost reductions to project customers, increasing competitiveness of the technology and reducing the levelised cost of energy from these projects.

CSIRO have identified further opportunities to reduce the cost of the field wiring and foundations. The costs of these concepts has been estimated and CSIRO is developing a further research project to explore these options in detail.

With the proof of concept completed, CSIRO will continue to develop the Camera array system, while looking for licensees to roll out the technology into commercial facilities. One option would be to install a camera array within a lambertian target on tower for a new commercial solar thermal project. This would be a low risk way to test the technology at scale, and should it be successful the technology is expected to reduce commissioning time, which could bring facilities online faster, decreasing costs and improving revenue, ultimately resulting in lower cost electricity.

Lessons Learnt

Lessons Learnt Report: Wind and Geotechnical Conditions for Heliostat Design

Project Name: Novel Concepts for Low Cost Small Heliostats in Remote Installations

Knowledge Category:	Technical
Knowledge Type:	Technology
Technology Type:	Concentrating Solar Thermal | Solar Tower Systems | Heliostats
State/Territory:	NSW

Key learning

In the design and optimisation of heliostat mechanical systems, the heliostat structure must withstand maximum wind loads and the heliostat foundation must support the structure under these conditions. Additionally the stiffness of the structure should be optimised so that the value of energy lost due to elastic deformation of the heliostat structure due to wind over its lifetime is not greater than the extra cost of increasing the stiffness.

Unfortunately, both soil mechanics and wind loads are complex systems which are often addressed using empirical or statistical approaches. The additional complication is that heliostats are not static structures in operation, and wind loads change depending on wind directions, angle of attack, planform, and influence of heliostats upstream.

Additionally, there is no single optimum heliostat design for all sites, as each site has unique wind and soil conditions. Thus, significant uncertainty remains which results in conservative costings and conservative safety factors being employed until the exact site conditions are known.

Implications for future projects

Heliostats used for research and testing of receivers should be designed and built with conservative approach so that optical quality of the surface and structural rigidity is high. For a research field it is unlikely that capital cost is going to be as critical as for commercial projects, as long as funding allocated appropriately.

Where possible, the design of a commercial heliostat should be optimised for a specific case with a defined field size, receiver type, location (topology and wind profile), and soil type. Onsite data collection and testing should be commenced as soon as possible (even in the feasibility stage) to reduce uncertainty and capital expenditure, which will ultimately reduce LCOE of the project.

Future projects that approach heliostat design tasks in a generic manner should not underestimate the number of variables and interconnectedness of heliostat systems.

Knowledge gap

The relationship between deformation of heliostats due to wind during operation and energy yield is not well understood.

Background

Objectives or project requirements

The project aimed to produce cost models for many locations and optimise the CSIRO design for deployment in remote locations. It became clear within the project that there were too many variables and cases to produce meaningful outcomes that could guide detailed engineering and development of prototypes.

Process undertaken

CSIRO attempted to reduce the number of variables/cases through making the following assumptions:

- In order to reduce the effect of different receiver designs and field sizes, the applications were reduced to a commercial molten salt tower of around 1.2 million m2 of heliostats (equivalent to around 100MWe with 8-12 hrs storage) similar to the Crescent Dunes plant.
- Wind loads for mechanical components were calculated using data reported by Peterka (1992), and the aspect ratio corrections according to Pfahl (2011). This data is for large, thin azimuth-elevation heliostats, which is not entirely accurate for the CSIRO design as the structure of the CSIRO heliostat would produce significant drag, and the planform of the heliostat changes when the heliostat rolls about the secondary axis. It was assumed that all sites had the same wind loads (which ignored impact of cyclonic regions).
- Two foundation types were costed; a reinforced concrete foundation that would be suitable in all soil types, and a driven pile foundation that would be only suitable in some soil conditions. The concrete foundation was very expensive but the certainty of its suitability was high, whereas the driven pile system was lower costs, but would need to be designed and tested on each site (and possibly even different designs within one site).

CSIRO set about the DFMA process and prototype design with DCI with the view that overall section profile, shape and design should be optimised first for material efficiency, manufacture and assembly. The uncertainty in wind loads and required rigidity will be reduced when the application of the heliostat is better defined, after which the design can be optimised by increasing or decreasing thicknesses of sections of components.

For example, in the design of the actuator support arms, section shapes were chosen that were low cost to manufacture, to place material away from the section axis, increasing rigidity of the structure, without interfering with the swept volume of the facet across the required range of motion. Once this section was defined, wall thickness could be varied from 0.9mm to 1.9mm to increase/decrease strength and rigidity without needing a change in the manufacture method or the remaining assembly.

Ongoing Work

CSIRO, ANU and University of Adelaide, through ASTRI have identified tracking error due to wind loads as a key area of interest. Additionally, commercial heliostat designers have begun some research in this space.

CSIRO is working with licensees of the CSIRO heliostat technology on a range of proposals where better defined boundary conditions allow some more certainty. However, site testing is expensive and difficult to complete at early project stages, which makes it hard for licensees to submit aggressive commercial offers.

Appendix

Keywords

Heliostat, CSIRO, Heliostat Control, Heliostat Calibration, Linear Actuator, Sun Tracking, DFMA, Rioglass Solar, Remote Installations, Camera Array, Diver Consolidated Industries, Automation, Solar Tower, Concentrated Solar Power, Concentrated Solar Thermal

Glossary of terms and acronyms

ARENA	Australian Renewable Energy Agency
Calibration (of heliostats)	A process of measuring, and correcting for, the imperfections in the manufacture and installation of heliostat mechanical systems
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSP	Concentrating Solar Power (often used interchangeably with CST)
CST	Concentrating Solar Thermal
DCI	Diver Consolidated Industries
Heliostat	Sun Tracking Mirror that reflects light to solar receiver
LCOE	Levelised Cost of Electricity: Present Value of all costs over the life of a plant divided by the present value of all energy produced by the power plant over its life.
MWe	Megawatts of electrical power output from a solar plant
Receiver	Array of tubes/pipes which are externally irradiated by the concentrated solar energy within which the heat transfer fluid flows
SolarPACES	Solar Power And Chemical Engineering Systems, an IEA collaborative program which organises annual conferences and coordinates programs to progress CST technologies.
TRL	Technology Readiness Level