STANWELL SOLAR POWER STATION PROJECT

David R. Mills and Christopher J. Dey
Department of Applied Physics, University of Sydney, Street or P.O. Box, The University of Sydney, Sydney,
New South Wales 2006, Australia, E-mail d.mills@physics.usyd.edu.au

Graham L. Morrison
School of Mechanical and Manufacturing Engineering, University of New South Wales, Sydney,
New South Wales 2052, Australia, E-mail g.morrison@unsw.edu.au

Abstract – In Australia, electric utilities have a legislative obligation to supply an additional 2% of generation from new renewable energy capacity by 2010, and there is also a demand for electricity for voluntary Green Power schemes. This paper describes the Compact Linear Fresnel Reflector (CLFR) being developed for installation at the Stanwell power station in Queensland as part of an Australian Greenhouse Office Renewable Energy Showcase Project. Stanwell Corporation Limited (SCL), Solahart International, Solsearch Pty. Ltd. and the Universities of Sydney and New South Wales are cooperating in the project, and this first plant being partly funded by the Australian Greenhouse Office. The solar plant will be attached to a 1440 MW(e) coal fired plant. The 17000 m$^2$ array will be the largest array in Australia, producing a peak of 13 MW of thermal energy which will offset the use of coal in the generation of electricity. It will use direct steam generation and will feed either steam or hot water at 265 °C directly into the power station preheating cycle. The CLFR system, first developed by the University of Sydney and Solsearch Pty. Ltd., is simple and offers small reflector size, low structural cost, fixed receiver position without moving joints, and non-cylindrical, highly ideal, receiver geometry. Initial installed plant costs are approximately US$1000 per kWe, but this includes the effect of high up-front design costs and the cost should drop substantially in the second and subsequent plants.

Keywords - Solar, solar thermal, solar thermal electric, renewable electricity

1. INTRODUCTION

In the design of solar thermal power plants there has been a tendency towards larger and larger scale systems to produce economies of scale and lower installation cost. However, with contiguous reflectors there are limits on the manageable size of such systems. Scaling up of parabolic trough or dish collectors for large solar thermal power systems is limited by wind loading problems and shading between adjacent concentrators. The aperture width of the LUZ parabolic trough collectors (Kearney et al. 1985, Jaffe et al. 1987) is 5 m and the adjacent rows were spaced by approximately 10 m. Larger units become progressively more difficult to install and clean. Trough technology is now being developed by Pilkington (Pilkington 1996), and work is proceeding on improvements to system components and maintenance in order to reduce system costs.

One promising option for the reduction of the cost of current parabolic trough solar thermal power systems is to change to direct steam generation in the absorber. This removes the need for heat exchangers between the collector working fluid (usually oil) and the power cycle fluid (usually water). There has been considerable progress with the design of direct steam generation collectors, however, the implementation of this concept in concentrators such as the LUZ trough collector is difficult because of the need for a flexible fluid coupling to the absorber and the requirement for turbulent flow in small diameter absorber pipes running for hundreds of meters. As the operating pressure of a direct steam generation collector will be in excess of 40 bar, the flexible hoses used in the existing hot oil working fluid collectors must be changed to rigid rotating couplings.

The concept of large reflectors being broken down into many Fresnel sub-elements to improve manageability was advanced by Baum et al. (1957), and in the 1960s, important development work was undertaken by the important solar pioneer Giovanni Francia (Francia, 1968) of the University of Genoa, who developed both linear Fresnel reflector systems and Fresnel point focus systems, the latter of which directly led to a point focus array at the Georgia Institute of Technology in the USA and ultimately to the well known Barstow ‘Power Tower’.
While point focus systems dominated Fresnel reflector development in the subsequent decades, there was development work carried out on linear Fresnel systems by the FMC company (Di Canio et al, 1979) on 10 and 100 MW plants in the late 1970s, although the work was stopped for lack of US DoE funding just as the first components were about to be field tested. The proponents claimed that the cost-effectiveness of the systems would have been better than the Power Tower systems under parallel development at the time.

2. COMPACT LINEAR FRESNEL REFLECTOR

A Fresnel system can be designed with a stationary absorber so that a high-pressure direct steam generating absorber does not need flexible couplings. The system can also be scaled up in size without increasing the aperture width of the mirror components. A large Fresnel system can be designed with only one absorber line for a collector aperture width of 50 m or more, however, as a Fresnel system is scaled up the spacing between the outer lines of mirrors must be increased to avoid shading. This is a problem for trough and dish systems as well; the ground coverage used in the LUZ trough arrays is only 33%. The limited ground coverage of a classical Fresnel system can be overcome by a new configuration called the Compact Linear Fresnel Reflector (CLFR).

CLFR technology is an alternative form of the Fresnel reflector field that has been heretofore overlooked. A simple linear Fresnel system has only one linear absorber on a single linear tower, and therefore there is no choice about the direction of orientation of a given reflector. But for technology supplying electricity in the multi-megawatt range, there will be many linear absorbers in the system. Thus, individual reflectors can have the option of directing reflected solar radiation to at least two absorbers in linear systems.

This additional variable in reflector orientation provides the means for much more densely packed arrays. This is not only because the boundary between continuous regions looking at one or the other reflector can be shifted and optimised as the sun moves during the day, but also because patterns of alternating row reflector inclination can be set up such that closely packed reflectors can be positioned with minimal shading and blocking, and also because domains associated with one or the other tower can enlarge or shrink with time to allow optimum collection. The interleaving of mirrors between two linear absorber lines is shown in Fig. 1.

**Figure 1**: Schematic diagram showing interleaving of mirror rows to achieve high site coverage without shading between adjacent mirrors.
This arrangement minimises beam blocking between adjacent reflectors and allows higher reflector densities and lower absorber tower heights to be used. The advantages of interleaving become stronger as the reflector density in the field increases.

Avoidance of large reflector spacings is an important cost issue when one considers the cost of ground preparation, array substructure, tower structure, and steam line cost. For installation next to an existing fossil fuel generating plant where one must retrofit to make a lower pollution steam source, low land usage is also important. Minimisation of steam line thermal losses is also an advantage.

The CLFR power plant concept proposed for the Stanwell project is intended to reduce costs in all elements of the solar array. The following features enhance the cost effectiveness of this system compared with trough technology:

- Reflectors mounted close to the ground are used to minimise structural costs.
- Costly sagged glass reflectors are replaced by elastically curved glass reflector.
- The absorber/heat transfer loop is isolated from the reflector field and does not move, thus avoiding the high cost of flexible high pressure lines or high pressure rotating joints required in trough and dish systems.
- Water/steam is used for heat transfer, and passive direct boiling heat transfer can be used to minimise parasitic pumping losses and the need for flow controllers. Steam supply may either be directly into the power plant steam drum or via a heat exchanger. Steam can also be supplied in a similar manner for power plant reheating cycles.
- A simple cavity absorber design has been evolved and tested at a component test facility at Sydney University.
- Low array maintenance costs due to ease of access for cleaning the ground mounted mirrors, and the capability to remove absorber panels without breaking into the heat transfer fluid circuit.

3. ABSORBER DESIGN

A CLFR system with a 50 m wide mirror array requires an absorber that has an aperture of the order of 1 m. A horizontal evacuated tube array was first investigated for this project (Mills and Morrison, 2000) and a close packed array of tubes without a reflector was found to be the most optically efficient configuration.

However, an absorber testing programme at the University of Sydney (Dey et al., 1999) has determined that for the relatively modest temperatures in the first commercial array (265°C - 280 °C) a simpler and less expensive inverted cavity flat plate absorber is superior in performance due to its high optical efficiency. If the cavity is closed from air movement, then the stagnant air layer under the absorber reduces the convective heat loss to low values. The long wave radiant heat loss must also be reduced by the use of a selective surface coating on the plate. Current technology selective coatings such as black chrome can be used at temperatures below 300 °C. There are air stable sputtered cermet surfaces being developed that are suitable for higher temperatures at the University of Sydney and elsewhere.

An inverted cavity absorber allows the use of large conventional steam pipes which can be attached to the plate. This is similar to the pipes used in conventional boilers and relatively inexpensive.

4. STANWELL CLFR SYSTEM

Stanwell Corporation, Solahart International, Solsearch Pty. Ltd. and the Universities of Sydney and New South Wales are working to commercialise solar energy by building a large CLFR solar thermal power generation plant at Stanwell Power Station near Rockhampton in Queensland. This plant, which will be the largest solar array in Australia, will produce a peak of 13 MW of thermal energy, which will offset the use of coal in the generation of electricity. The project is estimated to cost $7 million. Stanwell Corporation Limited (SCL), as manager for the project, has received a technology commercialisation grant of A$2 million from the Australian Greenhouse Office under the Greenhouse Showcase Program. The solar plant will be attached to a 1440 MW(e) coal fired power station owned by SCL as shown in Fig 2. The solar energy is to be
collected by more than 17000 m$^2$ of mirrors that will be built beside the power station.

The solar array will be a direct steam generation system and will feed steam or hot water directly into the power station steam cycle. The first CLFR plant will be used for preheating feedwater going into the reheating circuit, although subsequent plant will be able to be used for main boiler steam injection into the cold reheat line (Fig. 3).

The design steam delivery conditions for the Stanwell project are 265°C and 5 MPa wet steam. There is a slight peak capacity increase in the existing plant with preheating because turbine output is increased by avoidance of steam bleeding for feed water heating, but this is not a firm capacity increase because of the interruptibility of solar input.

The technology can, in principle, allow a peak output of 200MW(e) per km$^2$ of ground area, but the current cost optimum is to be pegged at about 140 MW(e) per km$^2$. As a comparison, an 80 MW(e) LS3 plant in California occupies about 1.35 km$^2$, about 60 MW(e) per km$^2$.

**Figure 2:** Artists impression of CLFR plant beside Stanwell power station.

**Figure 3:** Power station cycle with solar steam injection to the cold reheat line.
The detailed design approach is to minimise costs by using existing power block equipment and to maximise greenhouse gas savings by directly offsetting coal usage. Preheating will be supplied first at 180 °C, at which equivalent electrical output will be about 3.3 MWe peak, and then the plant will be reconnected to supply a higher temperature of 265°C for the re-heat stage of the steam cycle, at which equivalent electrical output will be 4.2 MWe.

Each of the four turbines can absorb about 30MWe of additional heat input, so there is considerable room for expansion without consideration of main boiler steam supply. The first 4.2 MWe plant is being built for $A7 million, which, depending upon exchange rate fluctuations, is approximately $US1000 per kWe, a lower figure than other direct solar technologies of which the authors have knowledge. It is believed that this cost will drop substantially in the first 30 MWe array.

5. COAL SAVER MARKET STRATEGY

Solar thermal electricity projects overseas have up to now built solar collectors and a power block as part of their project and thus have to develop the operation of both components, together. In this case, a relatively simple solar plant is to be integrated with an existing power station, allowing the project to concentrate on the solar part of the project.

In Mills and Dey (1999) we note that a fuel saving strategy made around replacement of coal is much more cost-effective at lowering emissions than one based around replacement of natural gas, yet industry strategies have tended to emphasise solar/gas hybrids up to now. We also suggest that developed countries should have more emphasis in solar thermal electricity industry planning because of the necessity for emissions reduction in such countries.

This project is particularly attractive because it offers a low risk, low cost path for commercialising solar thermal energy. The approach can be applied to any coal-fired power station in a sunny area, and although with horizontal arrays performance drops off at higher latitudes, the technology should be viable over most of the Australian mainland.

Around the world, there are hundreds of coal fired plants in good insolation areas, many with sufficient adjacent land area to accommodate a solar field of the size of the current largest solar thermal electric units of about 80 MW(e), and all of them with turbogenerators installed and an existing attachment to the electricity grid. This is a means whereby rapid expansion can take place relatively cheaply. Any solar retrofit to a typical coal fired plant will supply only a small percentage of its total electricity output, but cumulatively the production could rise to high levels quickly.

When such applications are exhausted, or else a new power station is being constructed, the array can be designed to supply saturated solar steam at 300°C - 360°C to the main boiler steam drum. Because of higher thermodynamic efficiency on conversion of heat to electricity, a further cost improvement is anticipated even though thermal collection from the array will be slightly reduced because of the higher operating temperature. This type of approach could be used for large remote area supply situations in Australia and elsewhere.

6. COST AND PERFORMANCE

Performance simulations for different tracking configurations using evacuated tube absorbers are reported in Mills and Morrison (2000). The performance of a CLFR array is compared with the LS3 LUZ collector and an optimised simulated parabolic dish are given in Table 1. The annual performance of the CLFR and the LS3 collectors are similar.

<table>
<thead>
<tr>
<th>Location</th>
<th>CLFR</th>
<th>LS3 array</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sydney</td>
<td>7.35</td>
<td>7.95</td>
</tr>
<tr>
<td>Wagga</td>
<td>11.4</td>
<td>11.0</td>
</tr>
<tr>
<td>Dubbo</td>
<td>10.2</td>
<td>11.0</td>
</tr>
<tr>
<td>Longreach</td>
<td>11.3</td>
<td></td>
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Preliminary cost analysis indicates that the CLFR system is the most cost effective system. Estimates of the generation LEC has been made for small 4.2 MW(e) peak plants. They are:

- US$0.084 per kWh(e) for the first $7million plant in the unexceptional Stanwell coastal
climate, based upon coal fuel cost avoidance of US$0.0065 per kWh(e).

- US$0.058 per kWh(e) for a second $5 million plant in the Stanwell location.

Australian financial conditions of discount rate of 8%, a depreciation rate of 6.7%, annual O&M equal to 2% of capital, and a lifetime of 25 years are used for the above calculations. The coal cost avoided does not include handling and waste disposal costs. High avoided coal costs will drop the LEC further, as will the use of larger array sizes and the production of steam for use in the main boiler where higher conversion efficiency can be realised.

These costs are for plants which have not the economies of scale expected in large production. Substantial drops in cost below US$0.058 per kWh(e) would be reasonable to expect in large scale production, but are not estimated in this paper.

As they are, costs such as these are comparable to wind generation in favourable sites. This technology and approach should allow STE to grow in developed country markets at rates similar to that being experienced by wind generation.

7. CONCLUSIONS

A new configuration for large-scale solar thermal electric concentrators, the CLFR, has been accepted for commercial demonstration in a solar array connected to the Stanwell coal fired power station in Queensland Australia. The technology is amenable to the retrofit of solar to coal and other fossil fuelled power stations in sunny areas internationally because it uses less land for a given output than other technologies. The first small project is to be delivered at approximately US$1000 per kW and subsequent projects are expected to be substantially lower in cost.

REFERENCES


Dey, C., Mills D.R. and Morrison G.L. (1999) Operation of a CLFR research apparatus. Internal report, School of Physics, University of Sydney, Australia.


