STANWELL SOLAR THERMAL POWER PROJECT

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Abstract - This paper describes the Compact Linear Fresnel Reflector (CLFR) concept being developed for installation at the Stanwell power station in Queensland as part of an Australian Greenhouse Office showcase project. The CLFR system is based on a number of parallel linear receivers elevated on towers that are close enough for individual mirror rows to have the option of directing reflected solar radiation to two alternative receivers. This additional variable in reflector orientation provides the means for much more densely packed arrays. Patterns of alternating mirror inclination can be set up such that shading and blocking are almost eliminated while ground coverage is maximised. The avoidance of large mirror row spacings and receiver heights is an important issue in determining the cost of ground preparation, array substructure cost, tower structure cost, steam line thermal losses, and steam line cost. The CLFR still delivers the benefits of the classical Fresnel reflector system, namely small reflector size, low structural cost, fixed receiver position without moving joints, and allowance for non-cylindrical receiver geometries.

1. INTRODUCTION

The most successful solar thermal development have been the linear Solar Energy Generating System (SEGS) plants installed by LUZ International Inc (Kearney et al. 1985, Jaffe et al. 1987). These plants use single-axis parabolic trough collectors that track the sun with a north/south axis of rotation. The concentration ratio is currently 26:1 and the absorber is a vacuum insulated flow tube that carried heat transfer oil. This technology is now being developed by Pilkington and Solel (Pilkington 1996), and work is proceeding on improvements to system components and maintenance and on direct steam generation in the solar array in order to reduce system costs. The tendency has been to produce larger and larger scale systems to produce economies of scale and lower installation cost, but with contiguous reflectors there are limits on manageable size. 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 is 5 m and the adjacent rows were spaced by approximately 10 m. Larger units also become progressively more difficult to install and clean.

Fig. 1: The linear Fresnel array built by G. Francia in 1963 at Marseilles. It achieved 60% efficiency at 100 atm. and 450°C.

The concept of large reflectors being broken down into many Fresnel sub-elements to improve manageability was first advanced by Baum et al. (1957), and in the 1960's, important development work was undertaken by Giovanni Francia (Francia, 1968) of the University of Genoa, who developed both linear Fresnel reflector systems (see Fig. 1) and Fresnel point focus systems, the latter of which directly led to a later 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 1970's, although the work was stopped for lack of 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.

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).

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 a pair of rigid rotating couplings for direct steam generation. A Fresnel system can be designed with a stationary absorber so that a high-pressure direct steam generating absorber does not need flexible couplings.

2. COMPACT LINEAR FRESNEL REFLECTOR

As a basic 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). The classical linear Fresnel system has only one raised linear absorber, and therefore there is no choice about the direction of orientation of a given reflector. However, for technology supplying electricity in the multi-Megawatt range, there will be many linear absorbers in the system. If the absorbers are close enough, then individual reflectors have the option of directing reflected solar radiation to at least two adjacent absorbers. This is the CLFR. This additional variable in reflector orientation allows much more densely packed arrays, not only because the boundary between continuous regions looking at one or the other absorber can be shifted and optimised as the sun moves during the day, but because patterns of alternating row reflector inclination can be set up such that closely packed reflectors can be positioned with minimal shading and blocking. The interleaving of mirrors between two linear absorber lines is shown in Fig. 2. The advantages of interleaving become stronger as the reflector density in the field increases.

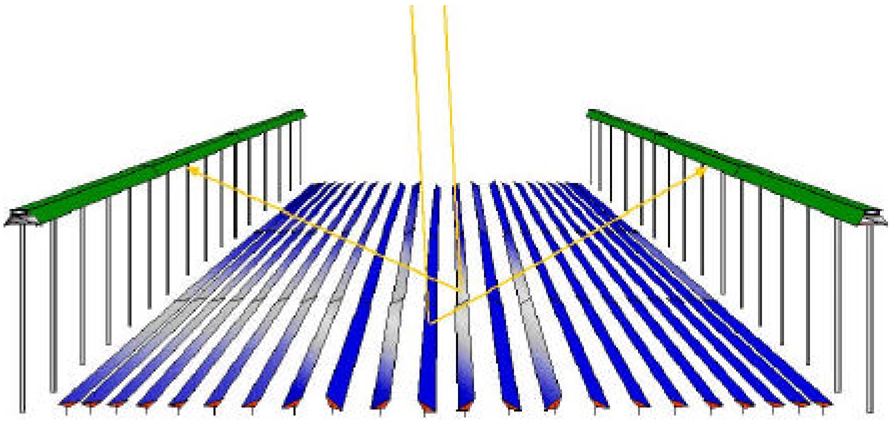

Fig. 2: Schematic diagram showing interleaving of mirror rows to achieve high site coverage without shading between adjacent mirrors.

Land or roof area cost is in many cases not a serious issue, but available area can be restricted in industrial or urban situations. Avoidance of large reflector spacing and high towers 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 the objective is the retrofit of a low pollution steam source. Minimisation of steam line thermal losses in also an advantage.

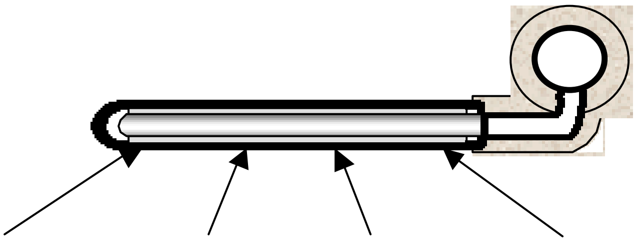

Fig. 3: Horizontal evacuated tube absorber with irradiation from the bottom.

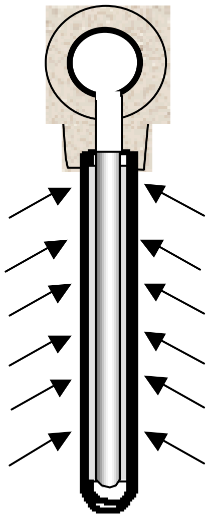

Fig. 4: Vertical evacuated tube absorber with irradiation on both sides.

The CLFR power plant concept 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:

- Flat or elastically curved glass reflectors mounted close to the ground are used to minimise structural costs. Elastically curved glass reflector replaces costly sagged glass reflectors.
- 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 rotating joints.
- 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. Direct steam return to the power plant steam drum or via a heat exchanger.
- An absorber composed of a pressure tube containing high pressure water, is mounted inside an advanced all-glass evacuated Dewar tube. The evacuated tubes exhibit very low radiative losses and are inexpensive, the current cost of a 1.2m long, 45mm diameter evacuated tube is approximately US$15.
- Low array maintenance costs due to ease of access for cleaning the ground mounted mirrors, and the capability to replace the single ended evacuated tubes from the absorber without breaking into the heat transfer fluid circuit.

2.1 Evacuated 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 has been investigated for this project. A close packed array of tubes without a reflector has been found to be the most optically efficient configuration. The evacuated tube arrays were developed as a result of the availability of low cost all-glass evacuated tubes. These tubes can be used to form a large aperture absorber by mounting a series of 1.4 m long tubes along the absorber as shown in Fig. 3 and Fig. 4 for horizontal and vertical arrays respectively. In these arrays the working fluid tubing is thick walled boiler tubing with 5 MPa working pressure. Boiling takes place in the vertical or near horizontal single ended branch tubes along the main header. Feed water is supplied to these branch tubes by flow along the bottom of the header while the steam is carried in the same header pipe above the feed water flow. A test rig (Dey et al. 1999) has been constructed to evaluate the performance of the heat exchange fin and the fluid circulation and boiling inside the near horizontal absorber tubes. The advantage of single ended evacuated tubes is that the tube can be changed without opening the pressure components in the system.

2.2 Inverted flat plate absorber design

An absorber based on an inverted flat plate with a stagnant air layer under the absorber to reduce convective heat loss is also being tested. The long wave radiant heat loss can be reduced by the use of a selective surface coating that can operate at high temp eratures. Current technology selective coatings such as black chrome can be used at temperatures below 300°C while there are air stable sputtered cermet surfaces being developed that are suitable for higher temperatures.

3. STANWELL CLFR SYSTEM

Stanwell Corporation, Solahart International, Solsearch Pty. Ltd. and the Universities of Sydney and New South Wales are working to commercialise solar electric generation by building a large solar thermal power 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 14 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 Renewable Energy Showcase Program. The solar plant will be attached to a 1440MW(e) coal fired power station owned by SCL as shown in Fig 5.

Fig. 5: Artists impression of CLFR plant beside Stanwell power station.

The first CLFR plant will be used for preheating feedwater, with design steam delivery conditions for the Stanwell project as 265°C and 5 MPa wet steam. Subsequent plant will be developed for main boiler steam injection in to the cold reheat line (see Fig. 6). 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 solar radiation will be collected by more than 17000 m^2 of mirrors focusing on to two absorber lines beside the power station. Subsequent plant will be developed for amin boiler steam injection in to the cold reheat line as shown in Fig 6. The technology can, in principle, allow a peak output of 200MW(e) per km^2 of ground area, but the current cost optimum is likely to be about 140MW(e) per km^2. As a comparison, an 80MW(e) Luz LS3 plant in California occupies about 1.35 km^2, or 60MW(e) per km^2. The design approach is to minimise costs by using existing power block equipment and to maximise Greenhouse benefits 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 4.4 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 4.4 MWe is being built for $A7 million, depending upon exchange rate fluctuations this 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 larger production versions.

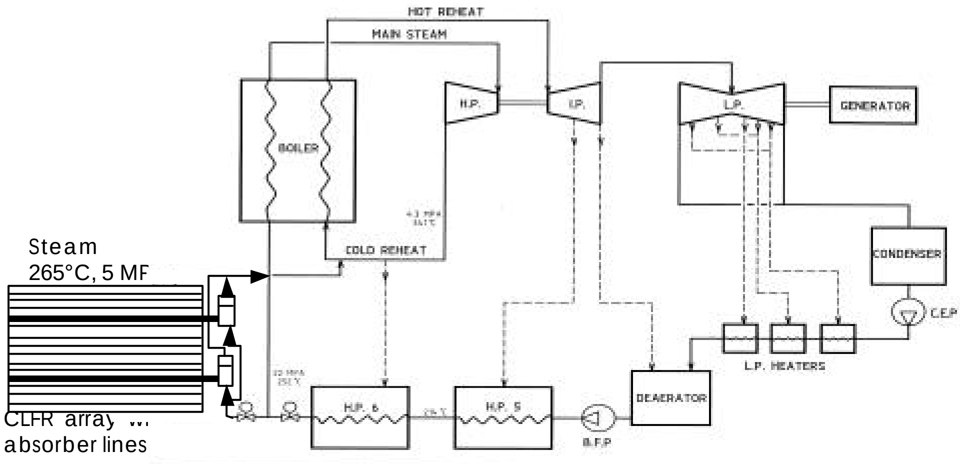

Fig. 6**:** Power station cycle with solar steam injection to the cold reheat line (stage 2).

3.1 Coal saver market strategy

This project is particularly attractive because it offers a low risk, low cost path for commercialising solar thermal electricity generation. In this case, a relatively simple solar plant is integrated with an existing power station, allowing the developers to concentrate on the solar part of the project. Solar thermal electricity developers have up to now built a new power block and grid connection as part of their project and thus have to develop and pay for this. Mills and Dey (1999) also 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 strategies have tended to emphasise solar/gas hybrids up to now.

This approach can be applied to any coal-fired power station in a sunny area, and although with horizontal reflector arrays performance drops off at higher latitudes, the technology should be viable over most of the Australian mainland. Performance simulations for different tracking configurations are reported in Mills and Morrison (1999). Around the world, there are hundreds of coal fired plants in high solar radiation 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). This is a means whereby rapid expansion can take place relatively cheaply. Any solar retrofit to a coal fired plant will supply only a small percentage of its total electricity output, but cumulatively the production could rise to high levels very 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 of 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 operation temperature. This type of approach could be used for large remote area supply situations in Australia. The performance of a CLFR array is compared with the LS3 LUZ collector and the ANU parabolic dish for various locations in Australia in Table 1. The annual performance of the CLFR and the LS3 collectors are similar. The dish gives the highest output however it is also the most expensive system to construct and the most difficult to operate due to its large unit size. Preliminary cost analysis indicates that the CLFR system is the most cost effective system.

An estimate of levelised dectric generation cost for a series of 4.2 MW(e) peak plants, (the current prototype size) for coal fuel cost avoidance of US$0.0065 per kWh(e) is:

- US$0.084/kWh(e) for the first $7million plant in the Stanwell coastal climate.
- US$0.058/kWh(e) for a second $5 million plant in the Stanwell climate.
- US$0.045/kWh(e) for a longer production run $4 million plant at Stanwell.
- US$0.031/kWh(e) for a longer production run $4 million plant in a good solar climate such as Hall's Creek.

Australian financial conditions of a discount rate of 8%, a depreciation rate of 6.7%, annual O&M equal to 2% of capital, and a lifetime of 25 years were 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 higher temperature steam for use in the main boiler where higher conversion efficiency can be realised. These generation costs 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.

Table 1: Annual thermal energy delivery for 300°C saturated steam delivery.

System	**Annual daily average energy delivery. (MJ/(m^2 day))**			
	Sydney	**Wagga**	**Dubbo**	**Longreach**
CLFR	7.35	7.95	11.4	11.3
Luz LS3 array	7.34	8.06	10.2	11.0
Parabolic dish	10.6	11.7	16.9	15.2

4. CONCLUSION

A new configuration for large-scale solar concentrators has been accepted for demonstration in a solar array connected to the Stanwell coal fired power station. The new CLFR array has the potential to deliver the lowest cost solar thermal electric power of all solar thermal power systems currently under investigation.

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