Concentrating Solar Power – Parabolic Trough with 20% gas boost (CSP-PT+20%)

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***Abstract*—Concentrating Solar Power – Parabolic Trough (CSP-PT) installations consist of linear parabolic mirrors which concentrate solar energy to heat tubes of oil or salt to high temperatures, typically to several hundred degrees centigrade. The thermal energy produced can be stored to enable continuous 24-hour operation of the turbine generator, but this option is generally expensive. As an alternative, a ~20% boost from natural gas can be deployed, which enables the plant to operate continuously. The main purpose of this paper is to investigate if the CSP-PT +20% gas boost technology would present the best option for Australia to address its growing energy demand.**

There is a lack of detailed literature on the topic, but an initial investigation has revealed that generating solar power using CSP-PT +20% gas would only be about twice as expensive as fossil derived power (10 US cents compared to 5 US cents per kWhr). Whether due to future shortage of supply or carbon taxation policy, the price of fossil fuel then only to double to make CSP-PT+ 20% gas technology very competitive – significantly more competitive than most other forms of renewable or non-renewable energy production.

Given a satisfactory emission trading scheme in Australia and globally, CSP-PT +20% could be the future energy choice for Australia, and other hot countries where sunshine and dry flat land are abundantly available. CSP-PT+20% sites would have to be located not too far away from existing power transmission lines, and where natural gas was locally available. An initial market price of ~10 US cents per kWhr would be required to make CSP-PT+20% technology economically viable, but this could fall substantially with economies of scale, as we progress gradually into a low carbon economic future.

Land with better soil quality and higher rainfall is able to produce biofuel, but frequent severe droughts and poor soil preclude this option for most of Australia. CSP-PT+20% technology thus presents a very attractive option in terms of providing energy security for Australia, and enabling transition to a low carbon economy. Future research is required to be carried out jointly by resource economists and engineers to see if CSP-PT+20% can be executed in Australia, even more cheaply than 10 US cents per kWhr. There may be some possibilities to reduce labour costs of manufacture if composite materials are used for the mirrors, for example.

Keywords - concentrating solar power parabolic trough

I. INTRODUCTION (HEADING 1)

It is now well established that increasing atmospheric concentration of greenhouse gases (GHGs) is responsible for global climate change and that one of the key contributing factors is heavy reliance of humans on fossil based fuels for their energy requirements [1]. Currently, about 80 per cent of global energy is produced from coal, oil and gas, with consumption projected to increase from 12 to 17 billion tonnes per year (oil equivalent) by 2030 [2].

A review of solar power developments across the world is provided by [3,4,5]. Interest in solar power has now commenced once again, after three decades of relative inactivity due to the abundance of cheap fossil fuel. The unfortunate consequence of this is that contributions to a global energy consumption of 464EJ in 2005 remained less than 1% from renewables (excluding hydro, biomass and nuclear), and less than 0.1% directly from solar energy [5]. Concentrating Solar Power (CSP) technology installed in the world deserts has the capacity to vastly and quickly increase the contribution made by solar energy to mitigate carbon induced climate change.

There are four main types of CSP technology currently available – heliostat tower (-HT), parabolic dish (-PD), Fresnel systems (-FR) and parabolic trough (-PT). The first three in addition to photovoltaic (PV) panels suited to domestic urban use are well described in the literature and have higher initial cost compared to CSP-PT, but may be attractive where land area is limited. For hot dry countries with large expanses of flat land, the first lowest cost choice for utility scale power is CSP-PT. If CSP-PT occupied an area of only 500km x 500km (ie. 1% of the world's desert area) it would provide the entire global energy requirement [6].

At present, approximately than eighty percent of the present world primary energy demand is provided by fossil fuel (coal, oil and gas) and results in approximately 9 billion tonnes (9 gigatonnes or 9 Pg) of carbon entering the atmosphere every year [1]. The other 20 percent of the worlds energy demand is provided by biomass, nuclear and hydroelectricity [7,8]. Currently, less than one percent is provided by other renewable energy forms such as solar, wind and geothermal [5,9]. Solar power has the potential to significantly increase this contribution. This paper attempts to provide the framework for assessing the economic viability of using this approach. [10] usefully conclude that one square metre of troughs in one year (in a hot desert environment) can produce the equivalent of one barrel of oil (1000kg equivalent of CO_2 if produced by burning coal, 400kg equivalent of CO_2 if produced by burning natural gas).

The contention of this paper is that CSP-PT, potentially with 20% natural gas augmentation if available (CSP-PT+20%), would probably represent the most economic method for power generation, particularly in hot arid regions of the world land is cheaply available. CSP-PT+20% also has the added advantage of greater reliability of supply of electricity to the customer, during periods of wet weather or unusually high demand.

II. Review

CSP-PT has proven to be the most reliable CSP technology, as demonstrated by nine installations in California with a combined capacity of 354 MW [5]. Connected to the grid during 1984–1991, the CSP-PT plants ranging from 14 to 80 MW generate around 400 GWh/yr at 10 to 12 US cents per kWhr [11,12]. The most recent CSP-PT plant to be completed is Acciona's 64-MW Nevada Solar One, near Las Vegas, Nevada, completed in 2007. The US has the largest CSP capacity in the world, followed by Germany, Spain and Japan. Most of the US capacity was installed in response to the energy crisis during the 1970s. From 1980 to 2007 there was little investment, but in the past three years, three new CSP plants have come online, and there is presently a further 77MW under construction. The goal by 2020 is to have approximately 24000MW of solar power capacity available in the US, roughly equally divided into solar thermal (CSP) and solar photovoltaic (PV) power [5].

Spain has led the way in Europe and opted for CSP-PT+20% technology similar to that described in this paper. As a result of a Spanish Royal decree in 2007, energy producers were given a 27.8 euro cent per kWhr subsidy, which has encouraged the development of several CSP-PT+20% enterprises across Spain. With similar subsidies, the potential of the Sahara Desert regions to supply all the energy requirements for Europe could be realised. The Trans-Mediterranean Renewable Energy Cooperation (TREC) is a voluntary group formed in 2003 and was an initiative of the Club of Rome. DESERTEC [13] is an Industrial Initiative (a consortium of blue-chip companies including ABB, Deutsche Bank, E.ON, Munich Re, RWE, and SIEMENS). Underpinned by detailed research at the German Aerospace Centre (DLR) and the US DoE, TREC/DESERTEC have commenced the construction of a EU$45 billion HVDC supergrid for the EUMENA region (European Union, Middle East and North Africa). Under the scheme, new CSP plants are under construction in Spain, Morocco, Algeria, Egypt, and Israel and more are planned under the Mediterranean Solar Plan (MSP), Arab League of Nations and the World Bank. Several HVDC transmission lines are already in place and Imera and others plan to build more. The EC is also providing funds for the supergrid. About 9 to 14 GW of CSP capacity is in the pipeline worldwide (World Bank and EER estimates).

III. Case Scenario for Australia

To achieve a low-carbon economy, along with the rest of the world, Australia needs to reduce its heavy dependence on fossil fuels [14,15,16]. Several targets have been set by government for GHG emissions reductions eg. 25% below 2000 levels by 2020 with a global agreement in place, or 5-15% reduction in any case. Under the Solar Flagships Program as part of the 'Clean Energy Initiative' [14], the Australian government has promised to invest Aus $ 1.5 billion in producing up to a 1000MW of energy using four utility scale solar power plants. Similar to Spain and the western United States, Australia has vast expanses of very dry flat land available for CSP-ST deployment. As a template for Australia, the case of the Solnova 1 CSP-PT 50 megawatt (MW) plant operating near Seville in Southern Spain is taken as a relevant example.

For the purposes of this brief paper, a CSP-PT+20% plant with an operating capacity of 50MW is assumed as the standard operational unit. 50MW is considered optimum, because if turbine generators are too large they have slow start-up times, and this can be inconvenient on days with fluctuating cloud cover. CSP-PT+20% installations are to be recommended in areas of the world where there are greater than 200 cloud-free days. The area of flat dry land in this scenario is assumed to be 100 hectares, or one million square metres. The cost of the land is assumed to be less than 10% of the overall capital investment, as is the case in many areas of Central Australia where there is very poor soil and very low rainfall.

Satellite derived DNI (Direct Normal Incidence) value of 3000kWhr/m2/yr is typical for much of the Australian inland continent. However, due to high cost of power transmission over long distances, CSP-PT plants would perhaps be better located closer to the coast where DNI is appreciably less. A conservative DNI only 2000kWhr/m2/yr is therefore assumed for the purposes of this exercise. An assumed overall efficiency factor for the plant of 6% (product of frontal area ratio of mirror to ground 30%, total system heat retention 45% and turbine efficiency 45%) then yields <u>120 million kW/hr per year</u> as the total marketable power available from the envisaged 50MW, 100 hectare plant. If a price of US 10 cents could be fixed for the sale price of electricity, the total yearly income would be approximately US$12 million. Assuming approximately 40 workers are required to operate the plant and labour plus maintenance costs are $4 million per year, an annual income of about US$8 million could be expected. If the initial capital investment was US$ 150 million, one 50MW CSP-PT+20% plant would represent a 5.4% return on investment. If 20% gas was not deployed, or some other more expensive solar power technology was utilised, return on investment could fall below 5% and solar operations may have to be subsidised by government.

Interestingly, the University of Melbourne Energy Research Institute have recently produced a study [17] in which they propose that 100% renewable energy power is technically possible by 2020. It is suggested in the report that CSP could provide up to 60% of the national grid demand. The estimated cost of the whole plan is 3% of GDP for ten years (ie. Aus $370 billion). If the Australian government opts to fund this, on environmental grounds the authors of this paper would certainly not oppose. However, we believe that the lower risk of CSP-PT+20% technology (perhaps one half of the investment cost) is more likely attract private investment initially, and ensure the long term survivability of solar projects in Australia.

IV. Conclusions and Policy Implications

The world community needs to celebrate the important milestones when solar energy alone provides 1%, 10% and then 20% of total world energy consumption, the latter hopefully achievable by 2020. The conclusion drawn from this brief paper is that that the CSP-PT+20% technology could contribute substantially towards this goal. Where natural gas was available, CSP-PT+20% would reduce economic risks associated with investments in solar power, in a market still well supplied with cheap fossil fuel. In the longer term, it would be hoped that the need for burning gas would be eliminated completely.

Such schemes are dependent upon an effective global Emissions Trading Scheme (ETS) which incorporates the full the environmental cost of fossil fuel based energy. As coal and oil start to become scarce, the price of fossil fuel will head towards US10 cent per kWhr in any case. The threat of this has made exploitation of remaining underground gas pockets around the world economically viable. The Coal Seam Gas (CSG) industry in Australia should not be discouraged, but it should take place fairly under a fair ETS which allows the renewable energy sector to also compete with traditional power generating industries on a level playing field. With solar power, Arizona and Utah alone could certainly power the rest of the US. Colder regions of the world would resort to wind and wave power.

The overall message is that as a world community we are ready, able and willing to do this. The solution is now with our politicians, with our democratically elected systems of government, and also with industry, most sectors of which are ready and quite prepared to work under a global ETS system. The science and technology is well advanced, and for the solar sector at least has been around for the best part of four decades. Refinements in the technologies will of inevitably take place and the price of CSP-PT derived energy will come down with economies of scale.

V. Future Work and a Role for Engineers

One of the developing aspects of concentrated solar power facility manufacture is in the use of advanced materials. One use of such materials is the manufacture of mirrors used in the solar concentrators. Such mirrors are required to both have good optical properties and be durable in outdoor conditions. [18] investigated a range of materials for manufacturing such mirrors. Over 50 materials were tested over eight test sites, in a variety of climatic conditions, in the USA and Europe. Materials tested including silvered glass, silvered polymers, aluminised polymers and anodised aluminium, in a range of outdoor and accelerated tests that emphasised optical performance and durability. Another material reported in this study as showing promise was a thin glass mirror being tested in Cologne. The authors also noted other materials such as low cost front surface mirrors based on coil aluminium, which aim to achieve reflectance values >= 94%.

Other areas likely to benefit from advances in material technology include facilities such as mirror frames and their supports, and track rails. Engineered fibre composites, for example, have potential to be used in the construction of such facilities through permitting innovative engineering design and construction through their strength, durability and light weight. As well as their well-known usage in areas like aircraft manufacture, engineered fibre composites have a range of civil engineering applications, such as bridge and floating walkway construction, and are also used in the rehabilitation of concrete and timber structures [19,20]. They may also be used for rail sleepers (for example, in the construction of tracks). Their properties enable them to provide considerable efficiencies to the construction process, thus reducing the energy required to construct facilities made from them. Work is also proceeding in their development from renewable sources such as plants. As long as such materials continue to remain relatively expensive, their future cost effectiveness will increase with further development and larger scale manufacture.

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