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SOLAR AIDED POWER GENERATION FROM COAL FIRED POWER STATIONS: “THERMSOLV” SOFTWARE

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Abstract:

Although the thermodynamic advantages of using solar energy to replace the bleed off steam in the regeneration system of Rankine cycle coal fired power stations has been proven theoretically, the practical techno/economic feasibility of the concept has yet to be confirmed relative to real power station applications. To investigate this concept further, a computer modelling software “THERMSOLV” was developed by Deakin University researchers, together with the support of the Victorian power industry and Australian Research Council (ARC). This newly developed software simulates the steam cycle to assess the techno/economic merit of the solar aided concept for various power station structures, locations and local electricity market conditions. Two case studies, one in Victoria Australia and one in Yunnan Province, China, have been carried out to show the application of the software. This paper reports the structure and functions of the software, and the results of the two case studies.

1. INTRODUCTION

The burning of fossil fuels to generate electricity is a major contributor to greenhouse gas emissions, primarily CO₂, which has recently been confirmed to be the cause of the global warming problem. With coal fired power stations the ratio of CO₂ emissions to electricity production is extremely high. Fossil fuel power generation is set to continue well into this century. However international greenhouse gas reduction agreements require substantial decreases in CO₂ emissions by the year 2010. Supplying the energy demands of today and the expected future increases requires immediate action to be taken if the targets proposed in these agreements are to be met. Renewable energies have the potential to assist in CO₂ reduction, although the economic viability of most large-scale renewable energy systems has not yet been confirmed.

Progress toward CO₂ reduction by the adaptation of green renewable energies, is currently less than about 2% of global energy production. With current trends it is forecast to increase to 4-5% by the year 2020. In general renewable energy generation technologies have failed to meet expectations of grid connected power generation contribution. With world energy consumption on the increase, and the majority of power generated being produced by fossil fuels, the question arises of how to keep up with the increasing demand for electricity, while reducing CO₂ emissions. Solar aided power generation for traditional coal and gas fired power stations is then proposed [1].
The basis of solar aided power generation technology (SAPGT) is to use solar thermal energy to replace the extracted bleed-off steam in regenerative Rankine power cycles. This extracted bleed-off steam is normally used to preheat the feedwater before it enters the boiler. It has the effect of increasing the thermal efficiency of the cycle, but at a cost of reducing work output of the turbine generator due to reduced steam mass flow. By utilising solar thermal energy to supply heat to the feedwater, the thermal efficiency of the steam cycle is maintained, while high-grade energy of the normally extracted bleed off steam is preserved to carry out more useful work within the turbine generator. Alternatively the amount of fuel to the boiler could be reduced, while maintaining the same generation output capacity, resulting in a proportional reduction of CO₂ emissions. Preliminary theoretical studies have concluded that the technology is potentially capable of assisting coal fired power stations to increase their efficiency by 2 to 32%, i.e. a reduction of green house gas emissions within the same range [2].

Although the thermodynamic advantages of the solar aided concept have been proven theoretically, the practical techno/economic feasibility of the concept has yet to be confirmed relative to real power station applications. To investigate this concept further, a computer modelling software “THERMSOLV” was developed by the authors at Deakin University. This newly developed software simulates the steam cycle to assess the techno/economic merit of the solar aided concept for various power station structures, locations and local electricity market conditions.

2. “THERMSOLV” SOFTWARE: STRUCTURE AND FUNCTION

The “THERMSOLV” software is written in the Visual Basic for Applications programming language, using Microsoft Excel as the base application. It consists of two main procedures: heat balance and thermal efficiency analysis for (traditional) Rankine cycle power stations including cycles operating with regeneration and/or reheat, and the “scenario” calculations for various solar aided options.

The user is able to enter details about the steam cycle structure of the power station that includes the number and type of feedwater heaters and number of reheat stages. The program then generates an energy/heat balance diagram of the power station steam cycle. The user can then check to see if this diagram matches the actual steam cycle of the power station, before continuing on to the next stage. Once the steam cycle structure has been confirmed, operating parameters such as: pressures, temperatures and mass flow rates of the steam at various points in the cycle are entered. The outcome of the analysis is then presented in the form of a report, which includes the net generator output, boiler load and thermal efficiency of the current steam cycle. The information in this report can then be used to verify if the data input is correct, before continuing with the solar aided analysis procedure.

In the solar aided analysis section of the program, all the required solar related and operational data is entered or selected. This includes local solar radiation intensity, information about commercially available solar collectors such as type, temperature range, efficiency and cost per m², and some accounting information like electricity
wholesale price per MWh, fuel cost per kWh of electricity generated and finance interest rate etc. The user is then ready to begin the solar aided analysis, enabling the costs/benefits involved with the SAPGT concept to be compared under different scenarios.

The program allows the user to choose between two options: a preselected scenario in which 100% replacement of all closed feedwater heaters is set, or a flexible scenario in which the user specifies what level of solar replacement they wish to have at each closed feedwater heater.

In the fixed scenario option the reporting is in two parts, the program will generate two reports. The first is the so-called “Q Report”, this specifies the area and type of the solar collector needed to complete the 100% replacement of all closed feedwater heaters. The ‘Q Report’ provides details of the costs, benefit/return and payback time of the solar aided replacement concept, where the boiler load is maintained at its original (fuel consumption) level. The saved steam is assumed to go through the turbine and generate additional power/electricity, so the benefit, or return on the investment required to build the solar aided system, is based on the sale of additional “green” electricity. Similarly the “W Report” provides details of costs, benefit/return and payback time of the solar aided replacement, but in this case the generator output is maintained at the original level, so that the boiler (fuel input) load is reduced. In the “W Report” the benefit, or return on the investment required to build the solar aided system, comes from the reduced fuel consumption, which is also proportional to a reduction in CO₂ emissions.

In the flexible scenario option the user determines how they are to replace the bleed-off steam. They have the capacity to select an individual feedwater heater or a number of feedwater heaters to be replaced. For each feedwater heater they can nominate a percentage replacement of the bleed off steam with solar input. Once bleed off steam replacement scenario is set the user can adjust the steam mass flow rate to the boiler, which effects the boiler load and turbine output. This allows the user to customise the level of fuel saving and/or additional electricity generated. With the SAPGT concept it is possible to generate additional power and reduce CO₂ emissions (save fuel) simultaneously. The outcome of this scenario is also presented in a report format.

3. CASE STUDIES WITH “THERMSOLV”

Two case studies have been undertaken using the developed “THERMSOLV” software. One is in Victoria, Australia and the other in Yunnan Province China. The related data used in the case studies are shown in Table 1.
Table 1

<table>
<thead>
<tr>
<th>Case study country location</th>
<th>Australia</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average insolation W/m²</td>
<td>790</td>
<td>824</td>
</tr>
<tr>
<td>Average sunshine hours per day</td>
<td>6</td>
<td>6.9</td>
</tr>
<tr>
<td>Fuel cost $/kWh</td>
<td>0.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Electricity peak wholesale price $/MWh</td>
<td>370</td>
<td>280</td>
</tr>
<tr>
<td>Cost of Land (for solar collectors) $/m²</td>
<td>Not considered in the case study</td>
<td>Not considered in the case study</td>
</tr>
<tr>
<td>Finance interest rate %</td>
<td>Not considered in the case study</td>
<td>Not considered in the case study</td>
</tr>
<tr>
<td>Insurance, depreciation, maintenance</td>
<td>Not considered in the case study</td>
<td>Not considered in the case study</td>
</tr>
</tbody>
</table>

The solar collectors information used in the case studies are given in Table 2.

The first case study was carried out on the generation Unit 3 of Loy Yang Power station, located in the Latrobe Valley, Victoria Australia. Which is a typical 500MWe brown coal fired power generation unit with one re-heater and 6 feedwater heaters (one of these is open type deaerator). Figure 1 shows the steam cycle structure diagram, which was generated by the “THERMSOLV” software for this case. Unaltered the unit originally generates 500.353MWe at the cycle thermal efficiency of 46.13% and with the boiler load of 1106.827 MWth..

Table 2. Collector data used in the case studies

<table>
<thead>
<tr>
<th>Collector</th>
<th>Temp. from °C</th>
<th>efficiency</th>
<th>cost $/m²</th>
<th>Collector</th>
<th>Temp. from °C</th>
<th>efficiency</th>
<th>cost $/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat plate</td>
<td>40</td>
<td>0.4</td>
<td>$75.00</td>
<td>Flat plate</td>
<td>40</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Vac. Tube</td>
<td>200</td>
<td>0.4</td>
<td>$110.00</td>
<td>Vac. Tube</td>
<td>200</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>CLFR*</td>
<td>250</td>
<td>0.3</td>
<td>$165.00</td>
<td>CLFR</td>
<td>250</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td>Concentrator</td>
<td>350</td>
<td>0.4</td>
<td>$200.00</td>
<td>Concentrator</td>
<td>350</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

* Compact Linear Fresnel Reflector

Three scenarios were examined with the THERMSOLV software:
1) 100% replacement of all the 5 closed feedwater heaters.
2) 10% replacement of all the 5 closed feedwater heaters and
3) 100% replacement of IPH2 feedwater heater, which is the first feedwater heater after the reheating.

The results (Q and E report) are shown in Table 3. It should be noted that by adjusting the mass flow rate to the boiler, the solar aided concept can help the power unit to generate more power while save on fuel costs by reducing fuel consumption, just like in the scenario 3.
Table 3. Results of the LoyYang power station study.

<table>
<thead>
<tr>
<th>Type of replacement</th>
<th>100% replacement of all closed feed heaters</th>
<th>10% replacement of all closed feed heaters</th>
<th>100% replacement of PH2 feedwater heater</th>
</tr>
</thead>
<tbody>
<tr>
<td>mode</td>
<td>Q report</td>
<td>E report</td>
<td>report</td>
</tr>
<tr>
<td>Gen. Output</td>
<td>572.5MWe</td>
<td>500MWe</td>
<td>507.34MWe</td>
</tr>
<tr>
<td>• Cycle eff. increase</td>
<td>6.65%</td>
<td>6.65%</td>
<td>0.64%</td>
</tr>
<tr>
<td>• Add. gen. cap</td>
<td>72.18MWe</td>
<td>0.0MWe</td>
<td>6.99MWe</td>
</tr>
<tr>
<td>• Add. Income</td>
<td>$58M/yr</td>
<td>$0.61M/yr</td>
<td>$5.6M/yr</td>
</tr>
<tr>
<td>• CO₂ reduction</td>
<td>0.0%/yr</td>
<td>3.15%/yr</td>
<td>0.0%/yr</td>
</tr>
<tr>
<td>• Fuel savings</td>
<td>$0/yr</td>
<td>$2.76M/yr</td>
<td>$268,253/yr</td>
</tr>
<tr>
<td>• Collector area</td>
<td>977,896m²</td>
<td>854,613m²</td>
<td>93,792m²</td>
</tr>
<tr>
<td>• Collector cost</td>
<td>$116.4M</td>
<td>$101.7M</td>
<td>$11.3M</td>
</tr>
<tr>
<td>• Payback</td>
<td>1.99 years</td>
<td>36.8 years</td>
<td>2 years</td>
</tr>
</tbody>
</table>

Figure 1. Steam cycle structure diagram, generated by THERMOSLOV, for Unit 3, Loy Yang Power.
Table 4. Results of the Yangzhonghai power station study.

<table>
<thead>
<tr>
<th>Type of replacement</th>
<th>mode</th>
<th>Gen. Output</th>
<th>Q report</th>
<th>E report</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% replacement of all closed feed heaters</td>
<td></td>
<td>236.04MWe</td>
<td>207.32MWe</td>
<td></td>
</tr>
<tr>
<td>• Cycle eff. increase</td>
<td></td>
<td>6.69%</td>
<td>6.69%</td>
<td></td>
</tr>
<tr>
<td>• Add. gen. cap</td>
<td></td>
<td>28.7MWe</td>
<td>0.0MWe</td>
<td></td>
</tr>
<tr>
<td>• Add.Income</td>
<td></td>
<td>$20.25M/yr</td>
<td>$0.0M/yr</td>
<td></td>
</tr>
<tr>
<td>• CO₂ reduction</td>
<td></td>
<td>0.0%/yr</td>
<td>3.50%/yr</td>
<td></td>
</tr>
<tr>
<td>• Fuel savings</td>
<td></td>
<td>$0/yr</td>
<td>$0.635M/yr</td>
<td></td>
</tr>
<tr>
<td>• Collector area</td>
<td></td>
<td>339,825m²</td>
<td>296,486m²</td>
<td></td>
</tr>
<tr>
<td>• Collector cost</td>
<td></td>
<td>$29.9M</td>
<td>$26.26M</td>
<td></td>
</tr>
<tr>
<td>• Payback</td>
<td></td>
<td>1.48 years</td>
<td>41.36 years</td>
<td></td>
</tr>
</tbody>
</table>

A similar case study is also carried out on generation Unit 2 of Yangzhonghai power station in Yunnan province, China. It is also brown coal fired, with 200MWe output, Figure 2 shows the steam cycle structure diagram by the “THERMSOLV” software for this case. This unit normally operates with a thermal efficiency of 48.29% and a boiler load of 482.4 MWth. The study results are shown in Table 4.

It can be seen from the case study that in both cases generating “green” electricity from the coal fired power station is possible with SAPGT. Sale of the additional electricity generated from the sun seems more economically sound than the fuel saving option. The purposes of the case studies are mainly to demonstrate the application of the software developed, so the results in above cases are not conclusive. Similar (or more comprehensive one) study should be carried out, with the help of the THERMSOLV, before any decisions are to be made for a particular case.

4. CONCLUSIONS

The THERMOSOLV software developed is capable of reporting the
technical and economic feasibility of the solar aided concept for various power stations within various locations.

The case studies using the “THERMOSOLV” proved that the solar aided power generation concept/technology is an effective method of utilising low-grade solar thermal energy, both technically and economically. Also the inherit variability of power output from stand-alone solar power stations is overcome without the need for elaborate and impractical energy storage facilities.

The cost of implementing such a system would remain relatively low, as existing infrastructure of a conventional power station would be utilised. The extra investment to install the solar collectors can be easily recovered by selling the extra electricity generated during the peak hours. The payback time is around 2 years. Savings in fuel, which would be directly proportional to CO₂ reductions, make this option attractive to current energy producers who is aiming to reduce greenhouse gas emissions, i.e. the social/environmental benefit. It will also be economically attractive if carbon tax or other CO₂ emission related costs are considered.

5. REFERENCES