Study on Configuration and Operation Strategies of Solar Aided Power Generation Plant

PhD Thesis

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Executive Summary

This thesis presents the outcomes of a study on the impact of configuration and operation strategies on the techno-economic performance of a Solar Aided Power Generation (SAPG) plant. An SAPG plant is a solar thermal hybrid power system. In such a power system, the solar thermal energy is used to displace the heat of the extraction steam in a regenerative Rankine cycle (RRC) power plant to preheat the feedwater to the boiler. The displaced extraction steam can, therefore, expand further in a steam turbine to generate power.

The research and development of SAPG technology started in the 1990s. However, previous studies mainly focus on identifying the advantages of SAPG technology, design and optimising the design of the SAPG plants, and comparing the economic performance of SAPG performance with other power generation technologies (e.g. solar alone power generation). Few studies on the operation of SAPG plants have been undertaken before. There are, therefore, four research questions that remain to be answered:

- How many possible SAPG plant configurations to connect the RRC plant and the solar field are available, and what is the impact of combinations of these possible configurations and operation strategies on adjusting the displaced extraction steam's

flow rate on an SAPG plant's technical performance?

- Should only concentrating solar collectors be used in SAPG plants to achieve better plant performance?
- What are the impacts of the operation of non-displaced feedwater heaters on the SAPG plant's performance?
- How should an SAPG plant be operated under different market conditions in order to maximize the plant's economic returns?

Therefore, the aim of this research is to advance the use of SAPG technology from the design and optimisation stages to its operation stage by addressing the four research questions above.

A pseudo-dynamic thermodynamic and economic model has been developed, validated and used as a tool in this study. In this model, the performance of an SAPG plant is simulated at a series of time intervals (i.e. 1 hour intervals). At each time interval, it is assumed that the SAPG plant is operated in a steady state. Furthermore, this model can simulate an SAPG plant with all its proposed configurations/structures and operation strategies/modes. In addition, a criterion that can be used to evaluate the economic profitability of an SAPG plant with different operation modes has been proposed. Based on this criterion, an optimal operation mode that can maximise plant's economic profitability will be determined and adopted to operate the plant.

The main conclusions drawn from this research are:

- An SAPG plant's technical performance is dependent on the combination of the plant's configuration and operation strategies. There are 12 such combinations identified for SAPG plants. It is found that combinations 2, 5 and 8 (detailed in Chapter 3) can enable the plant to achieve the maximum annual technical performance.
- Non-concentrating solar collectors can and should be used in SAPG plants as they are superior to concentrating collectors in terms of net land based solar to power efficiency and even economics in some cases.
- The operation of non-displaced feedwater heaters (i.e. adjusting the extraction steam flow rate to the non-displaced feedwater heaters when the solar input changes) does have an impact on an SAPG plant's technical performance. It was found that a "constant temperature" operation of the non-displaced feedwater heaters is generally more effective than a "constant mass flow" operation that is, however, easier to manage. The only exception for this finding is in rich solar resources areas.
- An SAPG plant can be operated in either power boosting or fuel saving mode at any given time. Different modes would give the SAPG plant different economic benefits under given market conditions (i.e. for on-grid tariffs and fuel prices). A new criterion termed "Relative Profitability" (RP) which links the plant's profitability with its operation mode has been proposed and developed in this study. Based on this criterion, a "mixed mode" operation has been developed: at a given time interval (e.g. 1 hour) the plant should be operated in either power boosting or fuel saving mode: whichever gives the higher RP. Through case studies, it has been demonstrated that mixed mode operation could guarantee the best economic outcomes for the SAPG plants over the single (power boosting or fuel saving) mode of operation in all kinds of market conditions.

This thesis has been submitted in publication format, as it includes journal articles that have either been published or are currently under review by international, reputable journals. The four articles that have been chosen here best demonstrate the outcomes of the study and so form the main part of this thesis. Additional background information and a literature review are provided to establish the context and significance of this work.

Declarations

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, at my university or any other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide.

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Ji Yun Qin

List of Publications

Journal Paper I:

J.Y. Qin, E. Hu, G.J. Nathan, *The performance of a Solar Aided Power Generation plant with diverse "configuration-operation" combinations*, Energy Conversion and Management, 124 (2016), 155-167.

Journal Paper II:

J.Y. Qin, E. Hu, G.J. Nathan, L. Chen, *Concentrating or non-concentrating solar collectors for Solar Aided Power Generation*, Energy Conversion and Management, 152 (2017), 281-290.

Journal Paper III:

J.Y. Qin, E. Hu, G.J. Nathan, *Impact of the operation of non-displaced feedwater heaters on the performance of Solar Aided Power Generation plants*, Energy Conversion and Management, 135 (2017), 1-8.

Journal Paper IV:

J.Y. Qin, E. Hu, G.J. Nathan, L. Chen, *Mixed mode operation for the Solar Aided Power Generation*, Applied Thermal Engineering, submitted Aug 2017-Manuscript number: ATE_2017_4805.

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Notation

CM	Constant mass flow rate
CT	Constant temperature
DNI	Direct normal irradiance
ET	Evacuated tube
FS	Fuel saving
FWH	Feedwater heater
HTF	Heat transfer fluid
LCOE	Levelized cost of energy
PB	Power boosting
PT	Parabolic trough
RRC	Regenerative Rankine cycle
SAPG	Solar Aided Power Generation
SP	Solar preheater
VT	Varying temperature