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ON THE OPTIMIZATION OF SOLAR-DRIVEN COMBINED CYCLES

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Combined cycles are an attractive option for the power generation industry due to their high efficiency (over 50%). Solar energy could serve as the high-temperature heat source driving a combined cycle. Fraidenraich et al. (1991) presented an optimization procedure for solar-driven combined cycles, using fixed values for the concentration ratio (C=2000) and the optical efficiency of the solar collection system. Increasing the concentration will both increase the receiver's thermal efficiency and reduce the collection optical efficiency, leading to an additional optimization step. We present a generic model to compute the efficiency of a heliostat field coupled to a CPC secondary concentrator, and a procedure that combines the optimization steps of both the solar and power-block parts of the system.
The total solar-to-electric efficiency of a solar thermal central receiver plant is:

$$\eta_{TOT} = \eta_{PB}\,\eta_{REC}\,\eta_{OPT}$$

The Combined Cycle power-block efficiency η_{PB} depends on the gas turbine inlet temperature, with the pressure ratio and the steam turbines taken as optimal (Fraidenraich et al. 91). The receiver efficiency η_{REC} depends on the temperature and flux concentration ratio. For a given concentration, the product $\eta_{PB} \cdot \eta_{REC}$ may be optimized over temperature, so that the intermediate thermal-to-electric efficiency depends on the concentration alone. The remaining unknown term is the optical efficiency associated with the heliostat field and secondary concentrator (if used).

The optical efficiency η_{OPT} is the fraction of collectible radiation falling on the heliostat field that is delivered into the receiver. We approximate, at any given moment, the spot formed by each heliostat on the target plane as an ellipse of uniform intensity (Rabl, 85). The fraction of the ellipse falling inside the aperture defines the optical efficiency. An integral over time yields the annual averaged efficiency. The effects of absorption losses in the primary and secondary (e.g., Yehezkel 93) are included. Varying the size of the aperture in this computation leads to the optical efficiency vs. geometric concentration relation. This completes the presentation of the overall solar-to-electricity efficiency as a function of concentration alone, and permits the final optimization stage.

The results of the optimization indicate that the optimal operation range is at high concentration ratios (above 10,000) and high receiver temperatures (about 1300°C). The annual averaged total efficiency η_{TOT} can reach close to 30%, compared with 10–15% for current low- and intermediate-concentration systems. This limit on the efficiency can be pushed even higher with significant improvements in collection methods. The variation of the efficiency with concentration is slow, so that operation around C=5000 involves only a small penalty in efficiency. Recent work at the Weizmann Institute suggests that operation at these high temperatures and concentration ratios is technically feasible.

References

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