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Design of a Novel Solar-Based Sustainable Energy System with Energy Storage

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I. Abstract

This research explores a solar-driven energy infrastructure integrated with thermal energy storage to meet community sustainability needs by generating electricity, heat, fresh water, and hydrogen. Evaluation using thermodynamics laws emphasizes energy and exergy analyses. Two different case studies have been carried out. The CSP plant's ability to produce electricity is the only subject of the first case study. This case study's energy and energy efficiencies are 31.66% and 33.36%, respectively. The second case study looks at how the production of hydrogen and clean water can be combined with the heating and cooling systems that generate power. 29,018.10 kg of hydrogen and 369,013.52 m3 of water are produced per day in this system. The energy and energy efficiencies reach 20.68% and 16.87%, respectively. Furthermore, an economic feasibility study shows LCOE of $0.13/kWh. The integrated energy system offers a path to developing greener communities in the long term by reducing carbon emissions.

II. System Description

This study contributes significantly to the development and implementation of a multigenerational solar-powered sustainable energy system amid global sustainability efforts.

In the first mode, the primary power generation subsystem utilizes water to generate superheated steam, driving a back pressure turbine to produce electricity. Simultaneously, a secondary subsystem employs a different working fluid and turbine configuration. However, when the thermal energy output from the primary subsystem exceeds a predetermined threshold, both subsystems collaborate, effectively utilizing excess heat from the primary system's exhaust steam. Conversely, when thermal energy falls below this threshold, priority shifts to the secondary subsystem for power generation, ensuring optimal efficiency and resource utilization at all times.

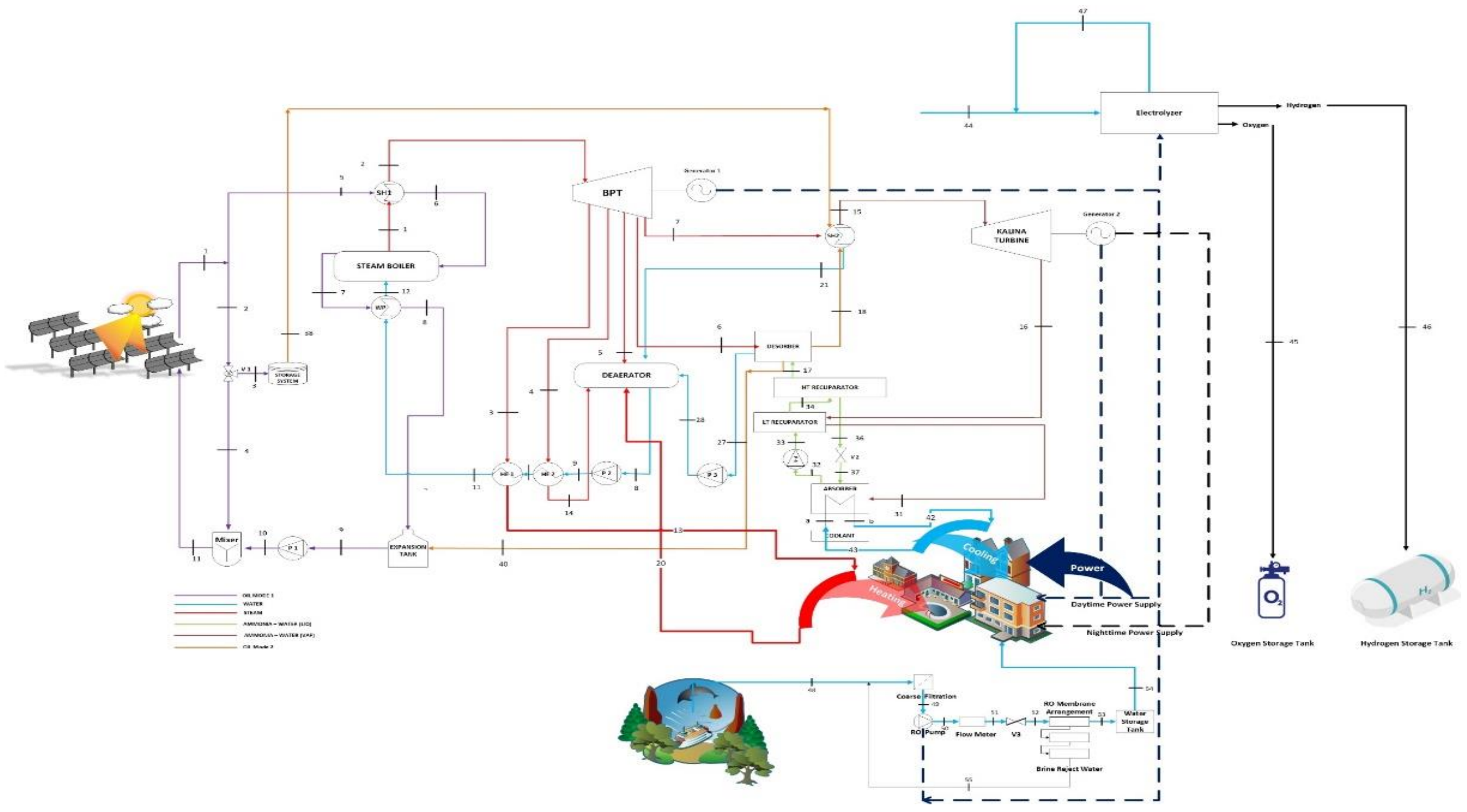


Figure 1. Schematic Representation of the Process Diagram for Case Study 2

The efficacy and versatility of the designed multigenerational system are thoroughly examined through two comprehensive case studies. In Case Study 1, the focus lies solely on electricity production, tailored to meet the specific needs of the targeted community. Meanwhile, Case Study 2 (Fig. 1) encompasses a broader spectrum of energy requirements by integrating additional functionalities such as hydrogen production, heating, cooling, and desalination alongside electricity generation.

In summary, this holistic approach underscores the system's capability to address diverse energy needs while promoting sustainability and resilience in the face of evolving energy landscapes.

III. Results and Discussion

For case study 1, the system's excellent performance in utilizing solar energy to produce electricity is demonstrated by the achieved overall energy and exergy efficiencies of 31.66% and 33.36%, respectively. Considering the extra integration of heating and cooling systems, hydrogen, and clean water production case study 2's overall energy and energy efficiencies of 29% and 23% show a strong performance.

The changes in hydrogen production versus solar intensity for this study are given in Figure 2.

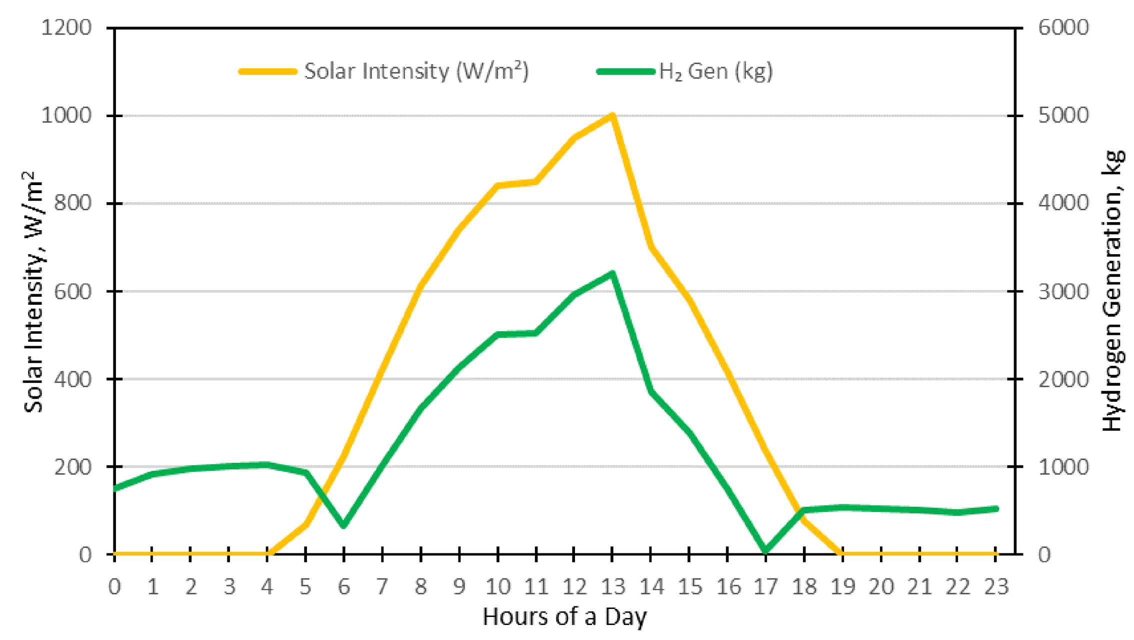
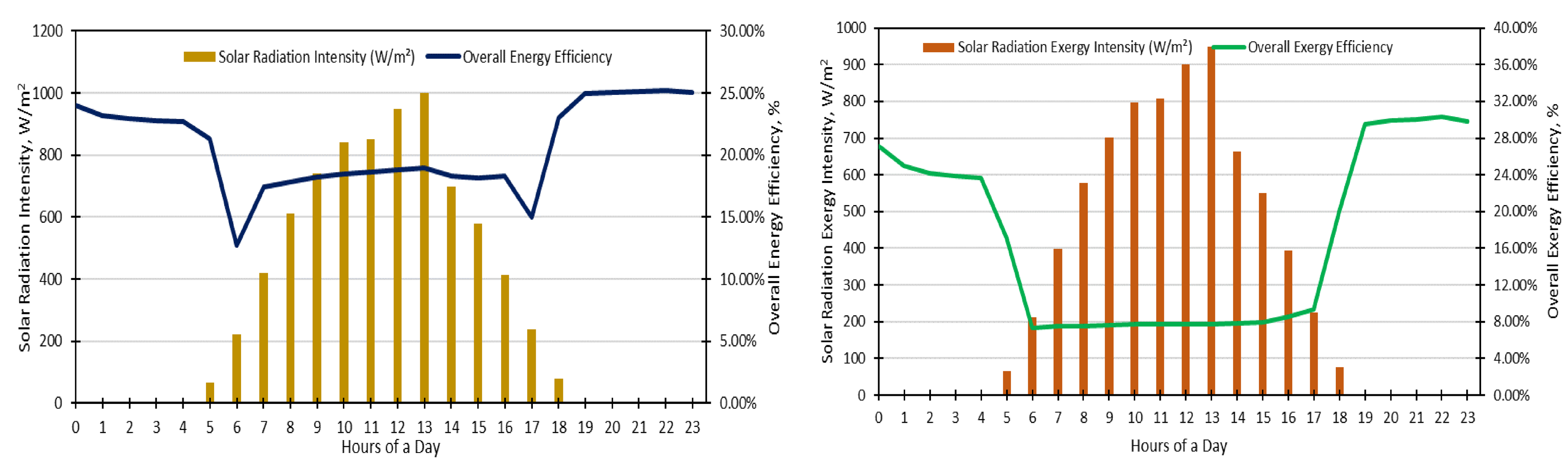


Figure 2. The changes in hydrogen production versus solar intensity for case study 2

Hydrogen production exhibits a close correlation with solar irradiance. Peaks in hydrogen production align with periods of maximum solar energy availability. The system's exceptional efficacy in generating hydrogen from excess electricity underscores the potential of utilizing solar energy for the sustainable and environmentally friendly production of hydrogen fuel.



(a) (b)

Figure 3. The overall energy (a) and exergy (b) efficiencies and energy of solar intensity for case study 2 according to hours of a day.

Figures 3a and 3b depict the energy and exergy efficiencies of Case Study 2's overall system. These visuals reveal how efficiency fluctuates with solar intensity, indicating the system's reliance on solar energy. During peak solar hours, efficiency is at its highest, showcasing the system's ability to convert solar energy into usable forms effectively. Conversely, efficiency drops during low solar intensity periods. This underscores solar energy's pivotal role in system performance, with efficiency decreasing at night.

IV. Conclusions

In conclusion, the study demonstrates the effectiveness of the concentrated solar power system. Case Study 1 achieved high overall energy and energy efficiencies of 31.66% and 33.36%, respectively. In Case Study 2, although energy and exergy efficiencies were slightly lower at 20.68% and 16.87%, the system's integration of heating, cooling, hydrogen, and clean water production proved holistic. Daily production included 29,018.10 kg of hydrogen and 369,013.52 m3 of clean water. Despite initial costs, the system offers significant long-term environmental and economic benefits for communities adopting sustainable energy solutions.

References

Caselles A, Sanz MT. The use of energies as a tool to stabilise climate and world population. International Journal of Global Warming; 23:91–109 (2021).

Cheng P, Liu W, Ma J, Zhang L, Jia L. Solar-powered rail transportation in China: Potential, scenario, and case. Energy; 245:123221 (2022).

Desai NB, Bandyopadhyay S. Optimization of concentrating solar thermal power plant based on parabolic trough collector. J Clean Prod; 89:262–71 (2015).

Fávero LP, de Freitas Souza R, Belfiore P, Luppe MR, Severo M. Global relationship between economic growth and CO2 emissions across time: A multilevel approach. International Journal of Global Warming; 26:38–63 (2022).

İnada AA, Arman S, Safaei B. A novel review on the efficiency of nanomaterials for solar energy storage systems. J Energy Storage; 55:105661 (2022).

Olabi AG, Wilberforce T, Abdelkareem MA. Fuel cell application in the automotive industry and future perspective. Energy; 214:118955 (2021).