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Techno-Economic Assessment of Multi-Field Solar Thermal Power Plants with Thermocline-based Storage

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Extended Abstract

Solar thermal power plants are potentially the foremost power generation alternative to non-renewable fossil fuel-based power plants. Unlike conventional coal-based power plants, these plants generate electricity more cleanly and sustainably. A solar thermal power plant converts the insolation into electrical power, and the associated intermittency of insolation due to the diurnal cycle and cloudy weather is reflected in the power generation. These fluctuations in power generation can be offset by the Thermal Energy Storage (TES) technologies. The most pronounced TES technologies are Two-tank storage and single-tank thermocline storage. The Two-tank storage is a mature technology, while single-tank thermocline storage is a state-of-the-art TES technology that can absorb the sudden thermal fluctuations due to the response time of controllers and actuators [1]. Despite the technological and economic benefits, single-tank thermocline storage is still in the development phase [2]. To bridge the gap and advance the thermocline TES adaptation in solar thermal power plants, the present study aims to model a 250 kWe constant output plant with the thermocline-based storage. Objectives of the present study are the performance and economic assessment of the solar thermal power plant with single-tank thermocline, two-tank and mixed-tank TES systems.

The multi-field solar thermal plants with three different TES options are modelled on the TRNSYS simulation software for the New Delhi, India location. All the solar thermal power plant components are designed to generate a 250 kWe constant electrical supply. The Solar Field is a combination of Parabolic Trough Collectors (PTCs) and Linear Fresnel Reflectors (LFRs) that concentrate and absorb the insolation. An indirect-direct thermocline storage system is employed with Therminol VP1 as heat transfer fluid and Solar Salt (60 % $NaNO_3$ + 40 % KNO_3) as storage material (Andasol plants, Spain, operate with similar indirect storage). The designed plant has the operating temperature range of 290 – 390 °C. Therminol VP-1 receives the heat from the PTC field, partially transfers it to the Power Block, and the rest of the heat from the PTC and LFR fields is stored in the Storage Unit, which is retrieved to operate the plant during non-sunshine hours. The Plant Load Factors (PLF) for the three defined storage configurations are determined. The annual PLF values for the mixed, thermocline, and two-tank storage are 0.32, 0.58, and 0.73, respectively. The PLF is a strong function of the round-trip efficiency of the Storage Unit. It is highest in the case of two-tank storage and lowest in the mixed storage. The thermocline storage in the present study has a round-trip efficiency of 60 %, which causes a lower PLF than two-tank storage. Further, economic analysis is performed on the different configurations. The Levelized Costs of Electricity (LCOE) obtained for mixed, thermocline, and two-tank storage are 1.80, 0.99, and 0.98 $/kWhe, respectively. The results inferred that although the thermocline storage is cost-effective, its lower round-trip efficiency leads to comparable LCOE with two-tank storage. At the comparable LCOE, the thermocline storage can absorb the sudden thermal fluctuations [1]. This study is performed for a demonstration-level plant (2024 reference year), which causes the higher LCOE values than the commercial plant. Future work will be to simulate different configurations and commercial-level scaled-up solar thermal power plants.

References

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