Dynamic Optimization of Solar Thermal Systems with Storage

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Solar energy will continue to become an increasingly important part of the energy mix. Its intermittency, however, is a challenge that must be overcome for solar to become a true replacement for fossil fuels. Therefore, energy storage, combined with effective control and dynamic optimization techniques will be essential to successful integration of solar and other intermittent renewables into the current energy infrastructure.

In this work, dynamic optimization using a 24-hour solar radiation forecast is used to improve performance of a solar-powered steam generation plant with thermal energy storage. The work considers a hybrid plant where natural gas is used to supplement solar energy to maintain a steady power supply. Two control approaches are compared. In the first, a standard control approach is used to maintain a constant solar field outlet temperature and a constant power output from solar energy. When sufficient stored thermal energy is not available, the supplemental fuel source is used. The other approach uses dynamic optimization, where a 24-hour forecast of available solar energy is used to predict future performance. Instead of controlling to a constant temperature, the optimal collection temperature is computed as a function of time. Hybrid operation, where the power output can be a combination of solar and fossil energy proves to be an essential part of operation. The ability to bypass storage is also beneficial as the optimal solution indicates that fluid stored at one temperature should not be mixed with fluid at another temperature due to the entropy that would be generated.

The solution to the dynamic optimization problem is obtained using a simultaneous method which converts the system of differential algebraic equations into a system of algebraic equations via orthogonal collocation on finite elements. The problem then becomes a nonlinear programming problem which is solved using an interior point algorithm.

Results indicate that the dynamic optimization approach is most effective on cloudy days, improving the solar share (the amount of energy delivered via solar energy) by up to sixty percent. This is largely attributed to reduced radiative heat losses in the solar field by virtue of shorter residence times and lower temperatures. The technique also improves performance on sunny days by approximately eight percent. A real-time implementation methodology is also discussed where the optimization strategy acts as a supervisory controller by feeding optimal temperature and power set-points to lower-level regulatory controllers. The system updates at regularly, taking the most recent state and forecast information into account. This methodology will help the system overcome the uncertainty in the forecast.

Extended Abstract: File Not Uploaded

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