Efficient NMPC Strategies for Thermal Stress Mitigation in Steam Turbines Powered by Solar Plants

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This work presents the development of efficient nonlinear model predictive control (NMPC) strategies for thermal stress management of steam turbines fed by solar plant steam, within the broader context of chemical engineering and energy production. Steam turbines in concentrated solar power plants face significant operational challenges due to frequent load variations and repeated start-ups, which induce thermal stress affecting rotor longevity and system reliability. The primary objective of the developed NMPC algorithms is to regulate electric power generation while constraining rotor thermal stress and wheel chamber pressure under dynamic operating conditions. The methodology employs advanced collocation methods for solving the dynamic optimization problem, significantly reducing computational time compared to traditional multiple-shooting approaches, while maintaining comparable accuracy. The NMPC formulation incorporates time-varying constraints and nonlinear disturbances within the prediction horizon, enabling effective adaptation to variable thermal loads. Special attention is given to the challenge of constraining rotor stress solely through wheel chamber pressure manipulation, as the feasible control region is limited by safety thresholds to avoid turbine trips or mechanical damage.

A two-stage turbine system comprising high-pressure and low-pressure units is considered, reflecting realistic industrial scenarios. The proposed control strategies successfully maintain power output targets and enforce physical constraints despite varying operating conditions. Validation of the updated rotor thermal model through open-loop simulations and comparisons with established solvers confirm improved accuracy and reliability in thermal behavior prediction. Comparative analysis of nonlinear solvers and optimization algorithms highlights trade-offs between computational efficiency and control performance, with fine-tuning of key parameters enhancing system response.

Future developments will focus on refining turbine models to better correlate wheel chamber pressure with thermal stress and incorporating additional manipulated variables such as throttling valve stroke. The scalable and flexible code structure facilitates iterative improvements and the simultaneous optimization of multiple turbine stages, aiming to bridge the gap between theoretical control design and practical industrial application.

This work contributes to extending turbine lifespan, improving operational safety, and enhancing energy efficiency in solar-driven power generation, addressing key challenges in thermal stress control. The integrated approach provides valuable insights for both researchers and practitioners in chemical engineering and related fields.

Keywords: *nonlinear model predictive control, thermal stress, steam turbines, solar power, collocation methods, turbine optimization*