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Optimization of pH Controller Performance for Industrial Cooling Towers via the PSO–MANFIS Hybrid Algorithm

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Abstract: The performance of pH controllers in industrial cooling towers is critical for maintaining optimal operational conditions and ensuring system efficiency. Industries such as the fertilizer, petrochemical, oil refinery, gas production, and power plant sectors rely on cooling towers, where poor pH regulation can lead to corrosion, scaling, and microbial growth. Traditional proportional–integral–derivative (PID) controllers are used for pH neutralization but often struggle with the cooling tower environments' dynamic and nonlinear nature, resulting in suboptimal performance and increased operational costs. A hybrid particle swarm optimization (PSO) algorithm combined with a multiple adaptive neuro-fuzzy inference system (MANFIS) was developed to address these challenges. The MANFIS leverages fuzzy logic and neural networks to handle nonlinear pH fluctuations, while PSO improves the convergence speed and solution accuracy. This hybrid approach optimized the PID controller parameters for real-time adaptive pH control. The methodology involved collecting open-loop pH data, deriving the system transfer function, designing the PID controller, and implementing the PSO–MANFIS algorithm to fine-tune PID gains. Three tuning methods—MATLAB Tuner, MANFIS, and PSO–MANFIS—were compared. The findings proved that the PSO–MANFIS approach markedly enhanced the closed-loop efficiency by reducing overshoot and enhancing the dynamic response. These findings demonstrate that the PSO–MANFIS approach effectively maintains pH levels within desired limits, reduces energy consumption, and minimizes chemical usage and the risk of mechanical equipment damage. This study provided valuable insights into optimizing pH control strategies in industrial cooling tower systems, offering a practical solution for improving efficiency and reliability.

Keywords: pH regulation; PID controller; cooling towers; MANFIS; PSO–MANFIS algorithm

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1. Introduction

Cooling towers are heat rejection systems based on the principle of extracting waste thermal energy from hot water and releasing it into the atmosphere using relatively cool and dry air [1]. Cooling towers enhance productivity and efficiency in industrial machines. Inadequate water treatment leads to corrosion and scaling in pipelines and basins, causing suboptimal heat transmission and ineffective cooling towers [2]. The pH parameter is a significant factor in industrial cooling towers. The pH level indicates the cooling water's acidity (when the pH is less than 7.1) and alkalinity (when the pH is more than 7.8). Acidic cooling water causes corrosion of mechanical equipment, while alkaline cooling water leads to scale formation on mechanical equipment [3]. Corrosion poses a significant concern