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Integrated Neural Network and Fuzzy Logic Control for Water Treatment Optimization in Power Generation Plants: A Conceptual Framework with Application Case Studies

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Abstract

This paper provides a complete engineering specification, simulation validation, and economic justification for an integrated Adaptive Neuro-Fuzzy Inference System (ANFIS) framework applied to four water treatment auxiliary sub-processes in a 600 MW coal-fired power station. For each application lime softening pH control, dissolved oxygen (DO) dosing, circulating cooling water (CCW) conductivity regulation, and condenser tube leakage detection the paper specifies the problem definition, input variable selection rationale, full ANFIS five-layer architecture, expert-driven rule generation procedure, Levenberg-Marquardt hybrid training algorithm, and the shared-feature-vector interface linking real-time control outputs to a parallel prognostic maintenance module. Simulation on a held-out six-month test set from 36 months of DCS historian data demonstrates that ANFIS outperforms PID, standalone Multi-Layer Perceptron (MLP), and standalone fuzzy logic baselines across all domains. Lime softening pH RMSE falls from 0.45 to 0.23 pH units; lime consumption decreases by 21.0%; operator interventions drop by 57.1%. Condenser tube leak detection accuracy improves from 72% to 94% with mean detection lag reduced from 8.5 to 2.2 hours. All reported improvements are confirmed statistically significant by paired t-tests or equivalent non-parametric tests ($p < 0.01$). Prognostic maintenance integration achieves 87% pump failure prediction accuracy with a 21-day average warning horizon. Economic analysis projects total annual savings of R 1,098,100 against a capital investment of R 1,420,000 (simple payback 1.29 years; five-year NPV R 2,845,000 at 10% discount rate), with a pessimistic sensitivity analysis confirming viability at payback 1.61 years when benefits are 20% below projection.

Keywords
ANFIS architecture; Mamdani fuzzy inference; Levenberg-Marquardt training; Hybrid Learning; Power Plant Water Treatment