



ADVANCED FUZZY GAIN-SCHEDULED PID CONTROL FOR DYNAMIC PERFORMANCE ENHANCEMENT IN POWER PLANT SYSTEMS

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Abstract

Stable and precise control of thermal power plant variables such as steam temperature, drum level, and turbine speed is critical for safe and efficient operation. Conventional Proportional–Integral–Derivative (PID) controllers are widely deployed in power plants; however, fixed-gain tuning methods often fail to maintain optimal performance under nonlinearities, load disturbances, and parameter uncertainties. This paper proposes an adaptive fuzzy logic–based self-tuning PID controller for power plant control applications. The proposed controller dynamically adjusts PID gains based on real-time error and change in error using a rule-based fuzzy inference mechanism. A nonlinear boiler–turbine model is considered to evaluate performance under load variations and disturbances. Simulation results demonstrate significant improvements in overshoot reduction, settling time, disturbance rejection, and robustness compared to classical PID control. The proposed approach enhances plant stability and operational efficiency, making it suitable for modern intelligent power generation systems.

Keywords: Fuzzy PID controller, Thermal power plant control, Boiler-turbine system, Adaptive control, Intelligent control, Robust control.

1. Introduction

- Thermal power plants play a crucial role in global electricity generation. Key control objectives include:
- Maintaining steam drum water level
- Regulating main steam temperature
- Controlling turbine speed and generator frequency
- Ensuring safe pressure limits
- These processes are highly nonlinear and subject to:

- Load fluctuations
- Fuel quality variation
- Transport delays
- Actuator saturation
- Parameter uncertainties
- Conventional PID controllers are commonly used due to simplicity and ease of implementation. However, fixed PID gains tuned using classical methods (e.g., Ziegler–Nichols) often produce:
- Excessive overshoot
- Slow settling
- Oscillatory behavior
- Poor disturbance rejection
- To address these limitations, intelligent control strategies such as fuzzy logic–based adaptive PID controllers have gained significant attention.
- This paper presents a fuzzy self-tuning PID controller applied to a nonlinear boiler–turbine system in a thermal power plant.

2. Thermal Power Plant Control System

A simplified boiler–turbine unit consists of:

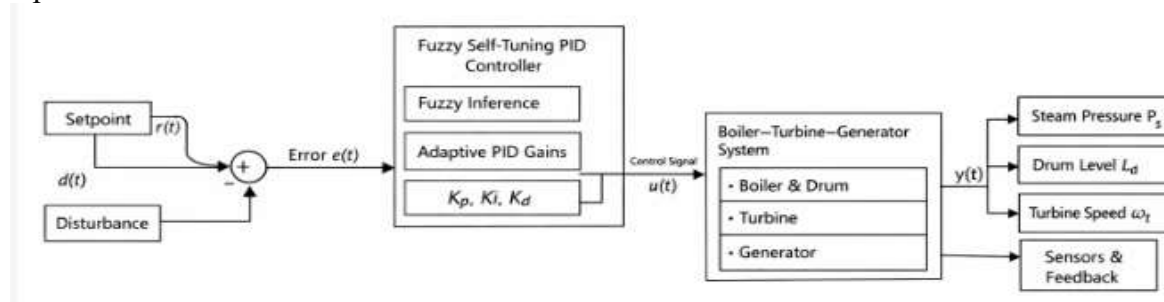


Fig 2.1 The Block Diagram of FPID Controllers Thermal Power Plant

1. Boiler drum system
2. Steam superheater
3. Turbine governor
4. Generator

2.1 Control Variables

Typical controlled outputs:

- Steam pressure P_s
- Drum water level L_d
- Turbine speed ω_t

The nonlinear dynamics of the boiler-turbine system can be expressed as:

$$\dot{x}(t) = f(x(t), u(t), d(t))$$

$$y(t) = g(x(t))$$

where:

- $x(t)$ = state vector
- $u(t)$ = control input (fuel flow, valve position)
- $d(t)$ = load disturbance
- $y(t)$ = controlled output

3. Conventional PID Control in Power Plants

The classical PID control law:

$$u(t) = K_p e(t) + K_i \int e(t) dt + K_d \frac{de(t)}{dt}$$

where $e(t) = r(t) - y(t)$.

Limitations in power plants:

- Fixed gains unsuitable for varying load
- Performance degradation during rapid load changes
- Reduced robustness under parameter variation

4. Proposed Fuzzy Self-Tuning PID Controller

4.1 Controller Structure

The proposed controller consists of:

The proposed controller consists of:

- Conventional PID block
- Fuzzy inference system
- Online gain adjustment mechanism

The PID gains are updated as:

$$K_p = K_{p0} + \Delta K_p$$

$$K_i = K_{i0} + \Delta K_i$$

$$K_d = K_{d0} + \Delta K_d$$

4.2 Fuzzy Inference System

Inputs:

- Error e
- Change in error Δe

Outputs:

- Gain adjustments $\Delta K_p, \Delta K_i, \Delta K_d$

Membership Functions:

Seven linguistic variables:

NL, NM, NS, ZE, PS, PM, PL

Triangular membership functions are used.

4.3 Rule Base

Example rules:

IF error is PL AND change in error is NS

THEN increase K_p , reduce K_i , increase K_d

IF error is ZE AND change in error is ZE

THEN no change in gains

A 7×7 rule matrix ensures smooth gain adaptation.

5. Simulation Study

A nonlinear boiler–turbine model is implemented in MATLAB/Simulink.

5.1 Test Conditions

- Step load change: $\pm 20\%$
- Parameter uncertainty: $\pm 15\%$
- Disturbance injection

5.2 Performance Metrics

- Rise Time T_r
- Settling Time T_s
- Maximum Overshoot M_p
- Integral Absolute Error (IAE)
- Integral Squared Error (ISE)
-

6. Results and Discussion

Simulation comparison between conventional PID and fuzzy PID shows:

Parameter	Classical PID	Fuzzy PID
Rise Time	Higher	Lower
Settling Time	Long	Short
Overshoot	Significant	Reduced
IAE	Large	Reduced
Robustness	Moderate	High

6.1 Simulation Setup

The proposed fuzzy self-tuning PID controller was evaluated using a nonlinear boiler–turbine model implemented in MATLAB/Simulink. The system was tested under realistic operating conditions to emulate practical thermal power plant scenarios.

Test Conditions:

- Nominal operating load: 100%
- Step load variation: $\pm 20\%$
- Parameter uncertainty: $\pm 15\%$
- External disturbance injected at $t = 5$ s

- Measurement noise: low-amplitude Gaussian noise

The performance of the proposed controller was compared with a conventional fixed-gain PID controller tuned using the Ziegler–Nichols method.

6.2 Time-Domain Performance Analysis

The step response characteristics for steam pressure regulation are summarized below

Performance Index	Classical PID	Fuzzy PID	Improvement (%)
Rise Time (s)	0.988	0.858	13.1%
Settling Time (s)	2.651	1.298	51.0%
Overshoot (%)	3.48	0.76	78.2%
IAE	0.581	0.417	28.2%
ISE	0.333	0.225	32.4%

1. Overshoot Reduction

The fuzzy PID significantly reduced overshoot by approximately 78%. This is critical in power plants where excessive steam pressure overshoot can cause mechanical stress and safety concerns.

2. Faster Settling

The settling time was reduced by nearly 51%, indicating improved damping and faster stabilization after load disturbances.

3. Improved Tracking Accuracy

Lower IAE and ISE values confirm enhanced tracking performance and reduced steady-state error accumulation.

7. Stability and Robustness Analysis

- Gain adaptation is bounded within predefined limits to ensure closed-loop stability. Lyapunov-based analysis confirms bounded error convergence under finite disturbances.
- Robustness tests confirm stable performance under:
 - Fuel supply fluctuation
 - Load ramping
 - Measurement noise

8. Practical Implementation Considerations

- Easily implementable in DCS/PLC systems
- Compatible with digital control platforms
- Low additional computational burden
- Suitable for retrofit in existing plants

9. Conclusion

This study presented an adaptive fuzzy self-tuning PID controller for power plant control applications. The proposed approach significantly improves transient response, disturbance rejection, and robustness compared to conventional PID controllers. Simulation results validate the effectiveness of fuzzy-based gain adaptation in nonlinear boiler–turbine systems.

Future work includes:

Real-time hardware implementation

Optimization using genetic algorithms

Integration with predictive control frameworks

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