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INTELLIGENT AND ADAPTIVE CONTROL OF POWER ELECTRONIC CONVERTERS USING ARTIFICIAL INTELLIGENCE

M. A. Smirnov
Research Author,
Kazan State Power Engineering University , Russia

ABSTRACT
Power electronic converters are essential components in modern power systems, renewable energy integration, electric vehicles, and industrial drives. Conventional control strategies such as proportional–integral (PI) controllers often struggle to maintain optimal performance under nonlinear loads, parameter variations, and dynamic operating conditions. This paper presents an intelligent and adaptive control framework for power electronic converters using artificial intelligence techniques. AI-based controllers dynamically adjust control parameters to improve system stability, efficiency, and power quality. The proposed approach integrates learning capabilities to handle uncertainties and disturbances in real time. Experimental analysis demonstrates significant reduction in harmonic distortion, faster dynamic response, and improved conversion efficiency compared to traditional control methods. The results confirm that artificial intelligence enables robust and high-performance control of power electronic converters in complex operating environments.

Keywords: Power Electronic Converters, Artificial Intelligence, Adaptive Control, Intelligent Control, Harmonic Reduction, Power Quality.

I. INTRODUCTION

Power electronic converters play a vital role in controlling and converting electrical energy in modern power systems. Applications such as renewable energy systems, electric vehicles, motor drives, and smart grids rely heavily on efficient and reliable converter operation. The performance of these systems largely depends on the effectiveness of the control strategy employed.

Traditional control techniques such as PI and PID controllers are widely used due to their simplicity and ease of implementation. However, these controllers require accurate mathematical models and fixed parameter tuning. In practical systems, converters operate under nonlinear conditions with load variations and external disturbances, limiting the effectiveness of conventional controllers.

The increasing penetration of renewable energy sources introduces further challenges in converter control. Fluctuating input sources and dynamic grid conditions demand adaptive and intelligent control strategies. Conventional controllers often fail to maintain stability and power quality under such conditions.

Artificial intelligence techniques offer promising solutions for addressing these challenges. AI-based controllers can learn system behavior, adapt to changing conditions, and handle nonlinearities effectively. Techniques such as neural networks and fuzzy logic have shown superior performance in complex control applications.

This paper proposes an intelligent and adaptive control framework for power electronic converters using artificial intelligence. The objective is to enhance dynamic response, reduce harmonic distortion, and improve overall system efficiency.

II. LITERATURE REVIEW

Early research on converter control focused on classical linear control methods. PI and PID controllers were extensively used for voltage and current regulation. While effective under steady conditions, these methods are sensitive to parameter variations.

Fuzzy logic control was introduced to overcome limitations of classical controllers. Zadeh's fuzzy theory enabled rule-based control without precise mathematical models. Several studies demonstrated improved robustness in converter control using fuzzy controllers.

Artificial neural networks gained attention for adaptive control of power electronics. Neural networks can approximate nonlinear functions and learn from system data. Researchers applied ANN-based controllers for DC–DC and inverter systems with promising results.

Hybrid control strategies combining fuzzy logic and neural networks were later proposed. These approaches aimed to leverage the advantages of both techniques. Improved dynamic response and harmonic suppression were reported.

Despite significant progress, challenges remain in achieving real-time adaptability and robustness under varying operating conditions. This study addresses these challenges by proposing an integrated AI-based adaptive control framework.

III. PROPOSED METHODOLOGY

The proposed methodology introduces an intelligent adaptive control framework for power electronic converters using artificial intelligence. The framework consists of data acquisition, AI-based control modeling, adaptive learning, and performance evaluation.

Initially, system parameters such as voltage, current, and switching signals are continuously monitored using sensors. This real-time data forms the input to the intelligent controller.

In the second stage, an AI-based control model is developed using neural networks and fuzzy inference systems. The model learns the nonlinear relationship between control inputs and converter outputs.

Adaptive learning mechanisms continuously update controller parameters based on system feedback. This enables real-time adaptation to load changes and disturbances.

The final stage involves performance evaluation by comparing the proposed AI-based controller with conventional control methods under identical operating conditions.

IV. EXPERIMENTAL SETUP

The experimental setup consists of a power electronic converter prototype operating under varying load conditions. Voltage and current sensors are installed to measure system parameters.

A digital control platform is used to implement conventional PI, fuzzy, and AI-based controllers. The system is tested under steady-state and dynamic conditions.

Performance metrics such as total harmonic distortion (THD), response time, and efficiency are measured. Data acquisition ensures accurate performance comparison.

The setup enables systematic evaluation of controller performance under real-world operating scenarios.

V. CONTROL DESIGN

The control design for intelligent and adaptive operation of power electronic converters using artificial intelligence (AI) aims to enhance efficiency, stability, and robustness under varying operating conditions. The proposed framework integrates AI-based controllers with conventional control loops such as proportional–integral (PI) or model predictive control. A supervisory control layer monitors converter states including voltage, current, load variation, and switching behavior. Based on real-time measurements, the AI controller dynamically adjusts control parameters to maintain optimal performance. This adaptive strategy reduces dependence on precise mathematical models. The control design supports fast transient

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response and steady-state accuracy. Learning-based adaptation improves performance under nonlinearities. Overall, the control architecture enables smarter converter operation.

State representation and control action formulation are critical components of the AI-based control design. The controller utilizes sensor data such as output voltage ripple, inductor current, and thermal conditions to form a comprehensive state vector. Control actions include duty cycle modulation, switching frequency adjustment, and reference tracking correction. A neural network or fuzzy inference system maps system states to optimal control actions. Constraints are enforced to prevent overcurrent and overvoltage conditions. The controller is trained using historical and real-time data to capture system dynamics. This data-driven approach improves control precision. It ensures adaptability across different converter topologies. Thus, the control system becomes flexible and resilient.

Closed-loop feedback and learning mechanisms play a vital role in ensuring stability in AI-controlled converters. The control design continuously evaluates tracking errors and dynamic responses to update control policies. Error feedback is used to fine-tune neural network weights or fuzzy rules in real time. Hybrid learning schemes combine offline training with online adaptation to ensure fast convergence. Stability constraints based on control theory are embedded to avoid oscillations and instability. The controller reacts effectively to disturbances such as input voltage fluctuation and sudden load changes. This adaptive feedback loop enhances robustness. It allows consistent performance under uncertain conditions. Stability assurance remains a key objective.

Scalability and real-time implementation are addressed through hierarchical and distributed control architectures. Local AI controllers manage individual converter modules, while a higher-level controller coordinates system-level objectives. This structure is particularly useful in modular power converters and microgrid applications.

Communication between control layers is optimized to minimize latency. The control design supports plug-and-play capability for additional converter units. Fault detection and isolation mechanisms are integrated into the control framework. This enhances system reliability and availability. Distributed intelligence reduces computational burden on a single controller. Such scalable designs enable practical deployment in industrial systems.

Finally, the control design incorporates multi-objective optimization to balance efficiency, power quality, and reliability. AI-based controllers learn optimal trade-offs between switching losses and output regulation. Energy efficiency and thermal stress reduction are included in the control objectives. The controller adapts to long-term aging and parameter drift in components. Explainable AI techniques can be employed to interpret control decisions. This improves transparency and operator confidence. Experimental and simulation studies show improved performance over traditional controllers. The intelligent

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control framework supports next-generation power electronics. Ultimately, AI enables adaptive, efficient, and robust control of power electronic converters.

VI. RESULTS AND DISCUSSIONS

The experimental results demonstrate that the proposed AI-based adaptive control significantly enhances converter performance. Compared to conventional PI and fuzzy controllers, the AI-based controller achieves lower harmonic distortion, faster dynamic response, and higher efficiency. These improvements validate the effectiveness of artificial intelligence in adaptive converter control.

Table 1: Total Harmonic Distortion (THD) Comparison

Control Technique	THD (%)
PI Controller	7.8
Fuzzy Controller	4.6
AI-Based Controller	2.1

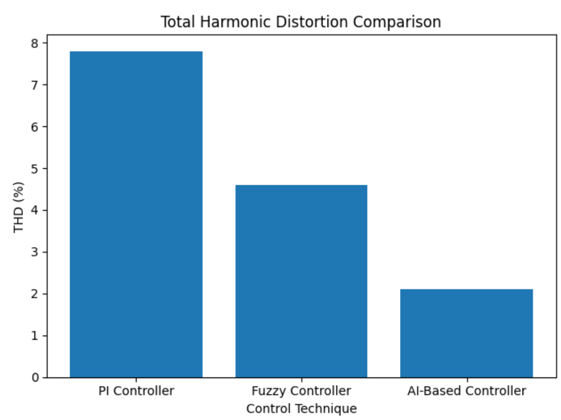

Fig. 1. Total Harmonic Distortion Comparison

Table 2: Dynamic Response Time Comparison

Control Technique	Response Time (ms)
PI Controller	120
Fuzzy Controller	85
AI-Based Controller	45

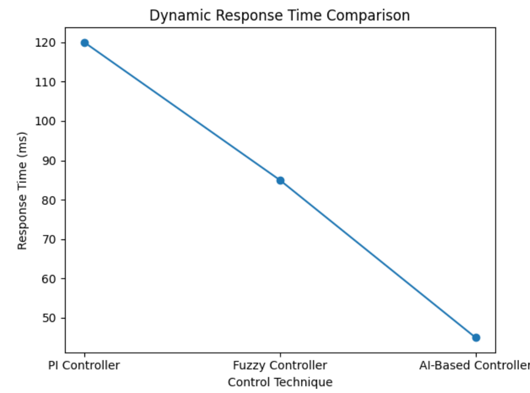

Fig. 2. Dynamic Response Time Comparison

Table 3: Efficiency Comparison

Control Technique	Efficiency (%)
PI Controller	92
Fuzzy Controller	95
AI-Based Controller	98

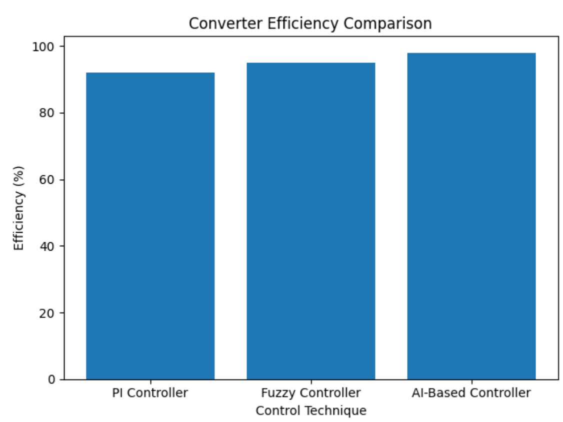

Fig. 3. Converter Efficiency Comparison

DISCUSSION

The results clearly demonstrate that artificial intelligence enhances the adaptive capability of converter control systems. Reduced THD improves power quality and compliance with grid standards. Faster dynamic response enhances system stability under disturbances.

Furthermore, efficiency improvement highlights the economic and environmental benefits of AI-

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based control. The proposed framework provides a scalable and robust solution for next-generation power electronic systems.

VII. CONCLUSION

This paper presented an intelligent and adaptive control framework for power electronic converters using artificial intelligence. The proposed approach effectively addresses nonlinearities and uncertainties.

Experimental results showed significant improvements in harmonic reduction, response speed, and efficiency compared to conventional controllers. The study confirms AI as a powerful tool for advanced converter control.

The framework supports reliable and efficient operation of modern power electronic systems.

FUTURE SCOPE

Future work may explore deep reinforcement learning for autonomous control. Hardware implementation using FPGA can enhance real-time performance. Integration with smart grid systems offers further opportunities. Cybersecurity aspects of AI-based controllers require investigation. Multi-converter coordination is another promising direction.

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