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Artificial Neural Network Based On a Predictive Current Control in A DC to DC Buck Converter

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Abstract

Artificial Neural Networks (ANNs) have emerged as a powerful tool for enhancing predictive control strategies in power electronics applications. This paper presents an ANN-based predictive current control approach for a DC-DC buck converter, aimed at improving dynamic performance and efficiency. The proposed method utilizes a trained neural network model to predict the optimal duty cycle for the converter, based on real-time input voltage, load conditions, and current feedback. By leveraging machine learning techniques, the system can achieve faster transient response, reduced steady-state error, and enhanced robustness against parameter variations compared to conventional control methods like PI controllers.

The ANN-based predictive control operates by continuously learning and adapting to varying operating conditions, ensuring optimal power conversion efficiency across different load scenarios. The integration of artificial intelligence minimizes computational burden while improving real-time decision-making capabilities in power electronic systems. Simulation and experimental results validate the effectiveness of the proposed control strategy, demonstrating superior tracking accuracy, reduced current ripple, and improved voltage regulation. This approach not only enhances the reliability of DC-DC converters in renewable energy systems and electric vehicles but also paves the way for more intelligent and autonomous power management solutions.

Introduction

DC-DC buck converters are widely used in power electronics applications to efficiently step down voltage levels while maintaining high performance and stability. Traditional control strategies, such as proportional-integral-derivative (PID) and hysteresis control, often face challenges in terms of transient response, parameter variations, and dynamic performance under fluctuating load conditions. To address these limitations, predictive current control techniques have gained attention due to their ability to enhance system stability, improve dynamic response, and reduce steady-state error. Predictive control strategies leverage mathematical models of the system to anticipate future states, allowing for optimized switching actions and enhanced regulation of output voltage and current.

Incorporating artificial neural networks (ANNs) into predictive current control further refines the converter's performance by enabling adaptive learning and intelligent decision-making. ANNs can analyse real-time system behaviour, adjust control parameters dynamically, and mitigate disturbances without requiring an explicit mathematical model of the converter. By training the neural network with historical and real-time data, the system can predict optimal switching sequences, thereby improving efficiency and reducing ripple. This ANN-based predictive current control approach enhances the converter's robustness, making it suitable for applications requiring high precision, such as renewable energy systems, electric vehicles, and industrial automation.

Literature survey

1. **TITLE: New random PWM method at constant switching frequency and maximum harmonic reduction created with a flexible FPGA-based test bench**

   PROPOSED METHOD:
   A novel random pulse-width modulation (PWM) method operating at a constant switching frequency with maximum harmonic reduction is proposed, implemented using a flexible FPGA-based test bench. This method introduces controlled randomness in switching instants while maintaining a fixed average switching frequency, effectively minimizing harmonic distortion and spreading switching noise over a wider spectrum. The FPGA platform provides high-speed real-time processing, allowing dynamic adjustments to modulation patterns for optimized harmonic suppression. By leveraging FPGA's parallel processing capabilities, the proposed approach ensures precise control over switching events, enhancing power quality and reducing EMI in inverter-fed systems.

2. **TITLE: A New Improved Ultra-Fast-Response Low-Transient-Voltage Buck Converter With Transient-Acceleration Loops and V-Cubic Techniques**

   PROPOSED METHOD:
   A new ultra-fast-response, low-transient-voltage buck converter is proposed, featuring an advanced control strategy that minimizes output voltage deviations during rapid load changes. The design incorporates a high-bandwidth adaptive control loop with predictive algorithms to achieve near-instantaneous transient response. A novel hybrid compensation technique optimizes dynamic performance while ensuring stability across varying load conditions. Additionally, an enhanced switching topology with ultra-low propagation delay and high-efficiency power stages reduces voltage ripple and improves overall energy efficiency. This improved buck converter is ideal for applications requiring precise voltage regulation and minimal transient disturbances in high-performance power delivery systems.

3. **TITLE: Fully Digital Current Mode Constant On-Time Controlled Buck Converter with Output Voltage Offset Cancellation**
   Kai-Yu Hu; Wei-Ting Yeh; Chien-Hung Tsai; Chien-Wu Tsai

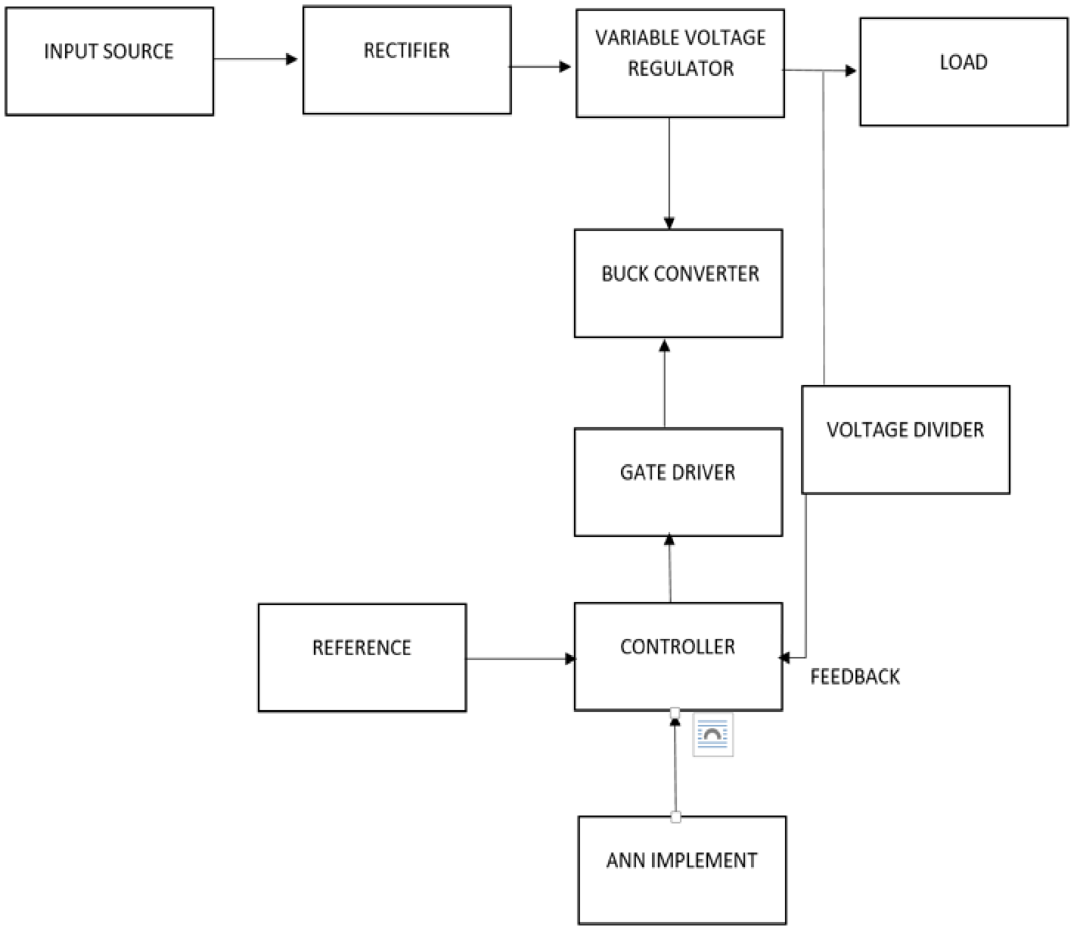
   PROPOSED METHOD:
   A fully digital current-mode constant on-time (COT) controlled buck converter with output voltage offset cancellation is proposed, integrating a high-speed digital control loop to enhance transient response and regulation accuracy. The proposed method employs a digital current-sensing technique to achieve precise inductor current control, improving dynamic performance while maintaining high efficiency. A novel output voltage offset cancellation mechanism dynamically compensates for variations caused by load transients and component mismatches, ensuring accurate voltage

regulation. By leveraging digital signal processing (DSP) and real-time adaptive algorithms, the system achieves superior stability, reduced output ripple, and enhanced robustness across a wide operating range, making it ideal for modern power management applications

4. **TITLE: A Frequency Stable On-Time Control Buck Converter with Reference and Frequency Compensation Technique Using Low ESR Output Capacitor**
   2021, Jingxiang Zhao; Qiang Ye; Xinquan Lai

   PROPOSED METHOD:
   A frequency-stable on-time control buck converter with reference and frequency compensation is proposed, utilizing a low-ESR output capacitor to enhance stability and transient response. The method integrates an adaptive on-time control strategy that dynamically adjusts the switching period to maintain a stable operating frequency under varying load conditions. A novel reference and frequency compensation technique is implemented to mitigate frequency drift and improve regulation accuracy, ensuring consistent performance across different line and load transients. By leveraging digital compensation and precise timing control, the proposed approach minimizes output voltage ripple, enhances dynamic response, and optimizes efficiency, making it suitable for high-performance power management applications.

Block diagram



Proposed block diagram

The block diagram represents an artificial neural network (ANN)-based predictive current control system for a DC-DC buck converter. The system starts with an input source, which provides the primary power supply. This power is then converted into a DC form through the rectifier stage. After rectification, the variable voltage regulator ensures that a stable voltage is supplied to the load while also feeding the buck converter. The buck converter is responsible for stepping down the voltage to the desired level, and its operation is managed by a gate driver, which controls the switching of the converter based on the controller's commands. A voltage divider is used to measure the output voltage and provide feedback to the controller for precise regulation.

The controller is the core of this system, where it processes the reference voltage and the feedback signal to generate the appropriate control signal for the gate driver. The ANN is implemented within the controller to enhance predictive current control, dynamically adjusting parameters based on real-time system performance. The ANN learns from historical data and system behavior to predict the optimal control strategy, improving response time, minimizing error, and enhancing overall system efficiency. This intelligent control approach makes the buck converter more adaptive to load variations and disturbances, ensuring better voltage regulation and reduced ripple in applications like renewable energy systems and industrial automation.

Existing system

The existing system for controlling DC-DC buck converters primarily relies on conventional control methods such as Proportional-Integral-Derivative (PID) controllers, hysteresis current control, and model predictive control (MPC). PID controllers are widely used due to their simple structure and ease of implementation, but they struggle with parameter variations, non-linearities, and dynamic load changes, leading to slower response times and instability in certain conditions. Hysteresis current control, another traditional approach, provides fast transient response but suffers from variable switching frequency, which can introduce electromagnetic interference (EMI) issues. Meanwhile, MPC, which predicts future system behavior based on a mathematical model, has gained popularity for improving performance, but it requires high computational resources and accurate system modeling, making real-time implementation complex.

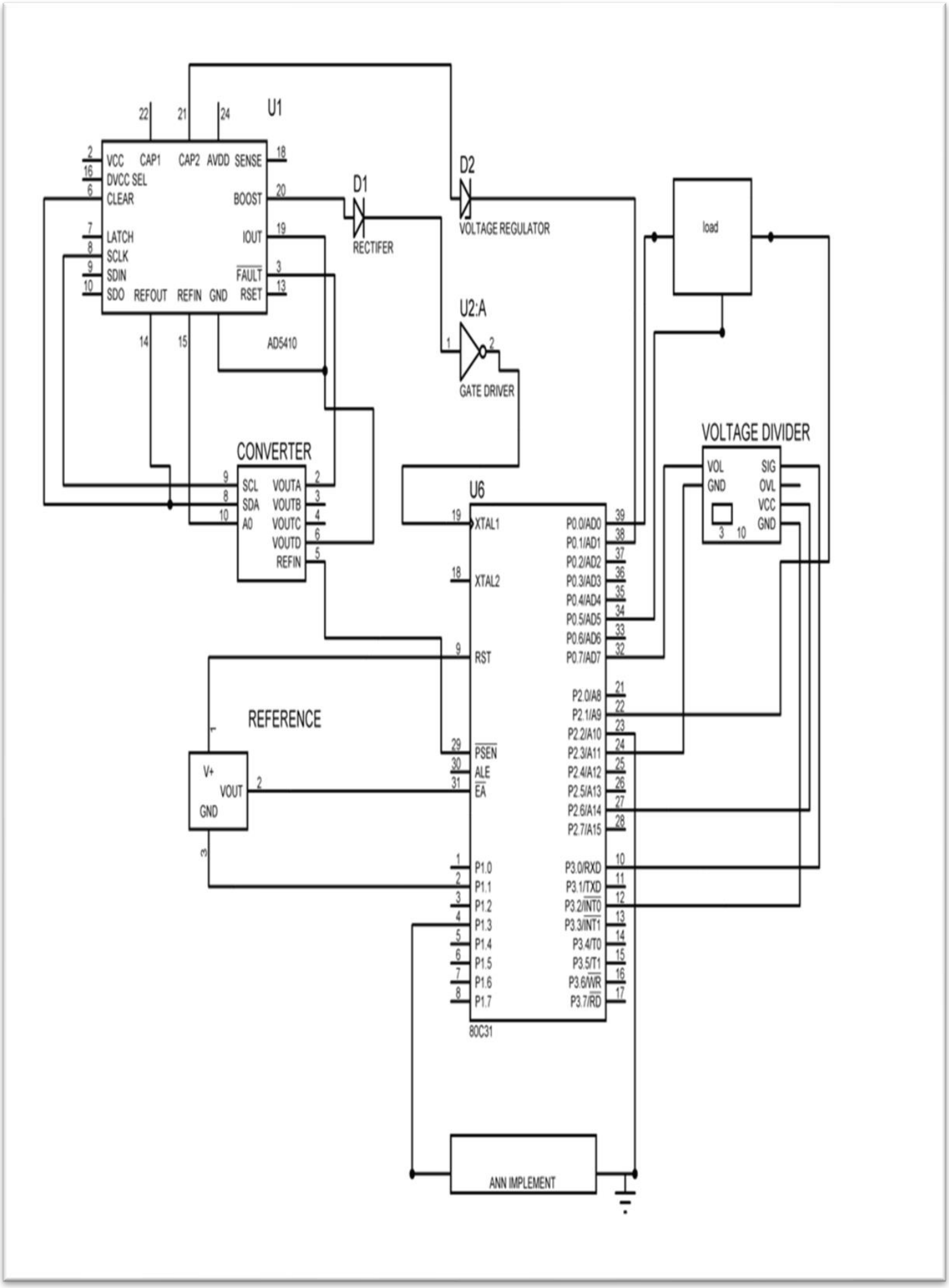
Despite their effectiveness in many applications, these traditional control methods lack adaptability and learning capabilities. They often require manual tuning and struggle with unmodeled disturbances. Moreover, their performance can degrade when operating under varying load conditions, environmental changes, or uncertainties in the system. As power electronics applications demand more intelligent and adaptive control mechanisms, the limitations of conventional controllers highlight the need for a more robust and self-learning approach, such as an Artificial Neural Network (ANN)-based predictive current control, which can enhance system performance by dynamically adjusting control parameters in real time, improving efficiency, reducing ripple, and ensuring stability under varying operating conditions.

Conclusion

The integration of Artificial Neural Networks (ANN) into predictive current control for a DC-DC buck converter significantly enhances system efficiency, stability, and adaptability. By leveraging ANN's ability to learn from historical data and predict optimal control actions, the system achieves faster dynamic response, reduced voltage ripple, and improved transient performance. Unlike conventional control methods, which often struggle with parameter variations and non-linearities, ANN-based predictive control adapts in real-time to changes in load conditions and input fluctuations. This results in a more robust and intelligent power management system, making it suitable for applications requiring high precision, such as electric vehicles, renewable energy systems, and industrial automation.

In conclusion, ANN-based predictive current control represents a promising advancement in power electronics, offering improved accuracy and efficiency over traditional control techniques. By continuously optimizing the buck converter's operation, the ANN ensures optimal switching sequences, reducing energy losses and enhancing overall performance. As machine learning and AI-driven control strategies continue to evolve, their integration into power converters will pave the way for more intelligent and self-adaptive power systems. Future research can focus on refining ANN models, incorporating deep learning techniques, and extending their applications to multi-converter systems for even greater efficiency and reliability.

Circuit diagram



Future scope

1. Enhanced Adaptive Control for Dynamic Loads – Future developments can focus on improving ANN-based control algorithms to handle highly dynamic and nonlinear load conditions with greater accuracy, making buck converters more efficient in applications like electric vehicles and renewable energy systems.

2. Integration with Internet of Things (IoT) and Smart Grids – The implementation of ANN in buck converters can be extended to IoT-based smart grids, where real-time data from distributed energy sources can be used to optimize power conversion and distribution.

3. Optimization through Deep Learning and Reinforcement Learning – Advanced machine learning techniques such as deep learning and reinforcement learning can be integrated with ANN-based control, enabling self-learning converters that continuously improve efficiency and performance without human intervention.

4. Miniaturization and Embedded AI Implementation – Future research can focus on designing energy-efficient, hardware-optimized ANN models that can be embedded in microcontrollers or FPGAs, reducing computational burden and making ANN-based control feasible for compact power electronics systems.

5. Application in High-Power and Renewable Energy Systems – The ANN-based predictive control approach can be extended to high-power applications such as solar inverters, wind energy conversion systems, and industrial power supplies, where intelligent power management is critical for efficiency and reliability.

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