

Research Paper

ADAPTIVE FUZZY LOGIC CONTROL OF A UNIVERSAL BRIDGELESS CHARGER FOR WIDE VOLTAGE BATTERY CHARGING SYSTEMS

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Abstract:- The increasing adoption of electric vehicles (EVs), portable energy storage systems, and industrial battery applications has accelerated the demand for efficient battery chargers capable of supporting wide output voltage ranges. Conventional battery chargers employing diode bridge rectifiers suffer from increased conduction losses, poor power quality, and reduced efficiency. This paper proposes an Adaptive Fuzzy Logic Controller (AFLC)-based universal bridgeless battery charger designed to operate over a wide battery voltage range while ensuring high efficiency and improved power quality. The proposed charger integrates a bridgeless power factor correction topology with an adaptive fuzzy control strategy to regulate charging current and output voltage under varying

input and battery conditions. The adaptive fuzzy controller dynamically adjusts control actions based on charging state, load variations, and voltage deviations, thereby overcoming the limitations of conventional proportional-integral controllers. The charger supports multiple battery chemistries and voltage ratings without requiring significant modifications. MATLAB/Simulink simulations demonstrate that the proposed approach achieves near-unity power factor, low total harmonic distortion (THD), fast transient response, and enhanced charging efficiency across a wide operating range. The obtained results validate the suitability of the proposed system for next-generation universal battery charging applications.

Keywords— Universal Battery Charger, Bridgeless Converter, Adaptive Fuzzy

Logic Control, Power Factor Correction, Wide Voltage Charging, Electric Vehicle Charger, Power Quality.

I. INTRODUCTION

The widespread deployment of rechargeable energy storage systems in electric transportation, consumer electronics, and renewable energy applications has created a need for versatile charging infrastructures capable of accommodating batteries with different voltage specifications. Traditional battery chargers are typically designed for fixed voltage ranges, limiting their applicability in multi-platform environments.

Bridgeless converter topologies have emerged as effective alternatives to conventional diode bridge rectifier-based chargers. By eliminating the front-end bridge rectifier, bridgeless converters reduce conduction losses, enhance efficiency, and improve thermal performance. Furthermore, these converters facilitate improved power factor correction and lower input current distortion.

Despite these advantages, maintaining stable charging performance over a wide output voltage range remains challenging due to varying battery characteristics and nonlinear operating conditions. Conventional PI controllers often require

retuning to maintain acceptable performance under different charging scenarios.

Fuzzy Logic Control has demonstrated superior capability in handling nonlinear systems without requiring accurate mathematical models. By incorporating adaptive mechanisms into fuzzy reasoning processes, controller performance can be further enhanced to accommodate dynamic system variations.

This paper presents an Adaptive Fuzzy Logic Controller-based universal bridgeless battery charger capable of charging batteries with diverse voltage ratings while maintaining high efficiency and excellent power quality characteristics.

II. LITERATURE REVIEW

Several battery charger topologies have been developed to address efficiency and power quality concerns. Conventional chargers employing diode bridge rectifiers exhibit increased conduction losses and generate significant harmonic distortion.

Bridgeless power factor correction converters have gained considerable attention due to their improved efficiency and reduced semiconductor losses. Researchers have investigated various bridgeless configurations, including boost, SEPIC, Cuk, and buck–boost topologies for battery charging applications.

Intelligent control techniques such as neural networks and fuzzy logic controllers have also been introduced to improve charging accuracy and dynamic performance. Fuzzy controllers provide robust operation under uncertain conditions but often rely on fixed membership functions and static rule bases.

Adaptive fuzzy control methods overcome these limitations by continuously modifying control parameters in response to operating conditions. However, limited research has explored their application in universal bridgeless chargers supporting wide battery voltage ranges. The proposed work addresses this research gap.

III. EXISTING SYSTEM

A. Conventional Battery Chargers

Existing charging systems commonly utilize bridge rectifiers followed by DC–DC converters controlled by PI regulators.

B. Limitations of Existing Systems

- High conduction losses due to bridge rectifier stages.
- Reduced charging efficiency.
- Poor input power factor.
- Higher input current harmonic distortion.

- Limited adaptability to different battery voltage levels.
- Requirement for controller retuning under varying operating conditions.
- Reduced transient performance.

IV. PROPOSED SYSTEM

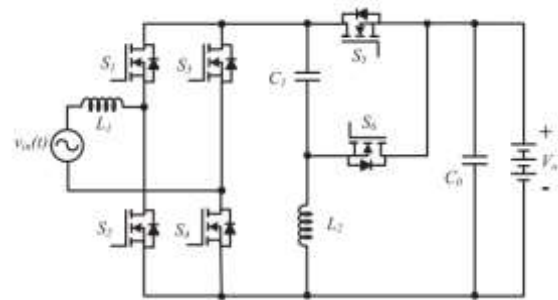


Fig. 1. Proposed nonisolated battery charger.

The proposed battery charger topology, illustrated in Fig. 1, comprises three pairs of semiconductor devices and passive components. Among them, S3 and S4 operate with the line frequency, while the remaining operate at switching frequency. The charger performs boost–buck operations along with the rectifier operation to maintain the desired dc voltage at the battery terminals. The charger's operating modes and switch states are changed according to the instantaneous input and battery voltages, as depicted in Fig. 2.

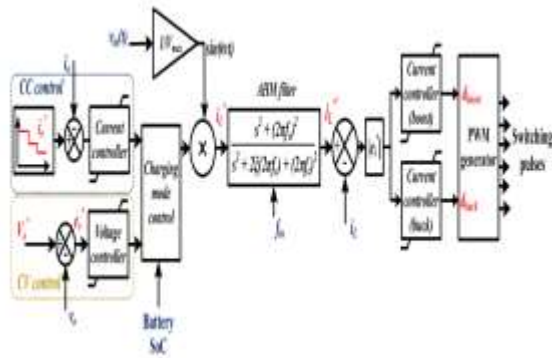


Fig. 2. Block diagram of the proposed controller.

If the supply voltage is less than the battery voltage, the charger is operated in the boost mode of operation; otherwise, the charger operates in buck mode. A small transition band is provided around the reference battery voltage for a smooth mode transition, and in this span, the converter operates with an unity gain. The switching states and conduction modes of the charger in boost, transition, and buck modes are illustrated in Fig. 3. S1–S4 and L1 form a boost-derived ac–dc converter, whereas S5, S6 and C1, L2 fulfill the buck operation. The charger frontend inductor acts as a boost inductor in boost mode, and the conduction modes for positive and negative boost modes, i.e., for $d_{\text{boost}} \times T_s$ and $(1 - d_{\text{boost}}) \times T_s$ period of times, are depicted in Fig. 3(a) and (b) and Fig. 3(e) and (f), respectively. The buck mode of operation remains the same for the positive and negative half of the inputs; conduction modes for $d_{\text{buck}} \times T_s$ and $(1 - d_{\text{buck}}) \times T_s$

periods are shown in Fig. 3(c) and (d), respectively. The boost and buck duty cycle in various operating modes are depicted in Fig. 2. As a result, during boost operation, there is no transition of buck switches, and the C1–L2 arm acts as a filter, further reducing voltage ripple. On the other hand, no transition of boost switches during buck mode, and the boost inductor acts as an input filter. In transition mode, the conduction path remains the same as Fig. 3(c) and (f) in the positive and negative cycles, respectively. Hence, the duty cycle of the charger is given by

$$d_{\text{charger}} = d_{\text{buck}} * (1 - d_{\text{boost}}).$$

The proposed charger is controlled with a dual-loop controller to maintain desired voltage/current and the unity power factor (UPF) at the output and input terminals, respectively. The outer loop controller monitors the battery voltage/current, whereas the inner loop monitors the input current and power factor. The charger is controlled with the designed controller, which has a common outer loop and distinct inner loops for boost and buck modes of operations depicted in Fig. 4. In general, the output power (P_o) of a single-phase charger at UPF is given by

$$P_o = \frac{V_{\text{max}} \times I_{\text{max}}}{2} (1 - \cos(2\omega t))$$

where V_{max} , I_{max} , and ω are the maximum voltage, maximum current, and angular frequency of the input power supply, respectively. This output power consists of a dc power and a second-order component, which are delivered to the battery and the output filter capacitor (C_o), respectively. The generated error voltage input to the outer voltage loop is given by

$$e_v^* = -\frac{V_{max} I_{max}}{4 V_o \omega C_o} \sin(2\omega t) = \Delta V_{Co}$$

Typically, the linear controllers such as proportional (P), integral (I), and PI controllers are employed as inner and outer controllers. In such cases, the same error voltage is processed through the voltage controller to generate a reference current for the inner loop. The generated reference current for inner current loop with a P, I, and PI controllers is given by

$$\begin{aligned} i_{L_f}^* &= \frac{V_{max} I_{max}}{8 V_o \omega C_o} [-k_{vP} (\cos(3\omega t) - \cos(\omega t))] \\ i_{L_d}^* &= \frac{V_{max} I_{max}}{8 V_o \omega C_o} \left[\frac{k_{vI}}{2\omega} (\sin(\omega t) - \sin(3\omega t)) \right] \\ i_{L_m}^* &= \frac{V_{max} I_{max}}{8 V_o \omega C_o} [-k_{vP} * (\cos(3\omega t) - \cos(\omega t)) \\ &\quad + \frac{k_{vI}}{2\omega} (\sin(\omega t) - \sin(3\omega t))] \end{aligned}$$

it is noticed that third harmonic component exists along with the fundamental component in the generated reference current; thereby, the controller forces the charger to extract the third harmonic current from the source. To circumvent this issue, an AHM technique is developed by exerting an optimal band-stop filter that

attenuates the existing dominant third harmonic in the generated reference current signal. The transfer function of an AHM in s-domain is given by

$$G_{AHM} = \frac{s^2 + (2\pi f_c)^2}{s^2 + 2\zeta \times (2\pi f_c) \times s + (2\pi f_c)^2}$$

The main function of AHM is to mitigate the dominant third harmonic component in the reference current and offers unit gain other than the corner frequency (f_c). The system is considered to be underdamped; therefore, damping ratio (ζ) varies from 0 to 1. The optimal design of an AHM depends on f_c and 3 dB bandwidth.

A. System Architecture

The proposed universal battery charger comprises:

- Single-phase AC supply.
- Input EMI filter.
- Bridgeless power factor correction stage.
- High-frequency DC-DC conversion stage.
- Battery charging interface.
- Adaptive Fuzzy Logic Controller.
- Voltage and current sensing circuits.

B. Objectives of the Proposed Controller

The AFLC is designed to:

- Maintain constant charging current during the CC mode.
- Regulate battery voltage during CV operation.
- Improve power factor.
- Minimize input current THD.
- Adapt to varying battery voltage levels.
- Enhance overall charger efficiency.

V. OPERATING PRINCIPLE

The charger operates under two primary charging stages.

A. Constant Current (CC) Mode

During initial charging, the controller regulates output current to maintain the desired charging rate irrespective of battery voltage variations.

B. Constant Voltage (CV) Mode

As the battery approaches full charge, the controller transitions to voltage regulation mode to prevent overcharging and improve battery lifespan.

The adaptive fuzzy controller supervises this transition while continuously optimizing control performance.

VI. ADAPTIVE FUZZY LOGIC CONTROLLER DESIGN

A. Controller Inputs

The AFLC receives:

- Voltage error:

$$[e(k) = V_{ref} - V_o]$$

- Change in voltage error:

$$[\Delta e(k) = e(k) - e(k-1)]$$

B. Controller Output

The fuzzy controller generates duty cycle adjustments for converter switching devices.

C. Membership Functions

Seven linguistic variables are utilized:

- Negative Big (NB)
- Negative Medium (NM)
- Negative Small (NS)
- Zero (ZE)
- Positive Small (PS)
- Positive Medium (PM)
- Positive Big (PB)

D. Adaptive Mechanism

The adaptive unit modifies scaling factors and membership boundaries according to operating conditions, thereby improving control accuracy and robustness.

E. Sample Fuzzy Rules

- IF error is PB AND change in error is PS, THEN decrease duty cycle moderately.
- IF error is ZE AND change in error is ZE, THEN maintain current duty cycle.
- IF error is NB AND change in error is NM, THEN increase duty cycle significantly.

VII. MATHEMATICAL MODELING

A. Power Factor

$$PF = \frac{P}{V_{rms} I_{rms}}$$

where:

- (P) = Active power,
- (V_{rms}) = RMS supply voltage,
- (I_{rms}) = RMS input current.

B. Charging Efficiency

$$\eta = \frac{P_{out}}{P_{in}} \times 100$$

where:

- (P_{out}) = Battery charging power,
- (P_{in}) = Input power.

C. Total Harmonic Distortion

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \times 100$$

where:

- (I_1) = Fundamental current component,
- (I_n) = Harmonic current components.

VIII. SIMULATION RESULTS AND DISCUSSION

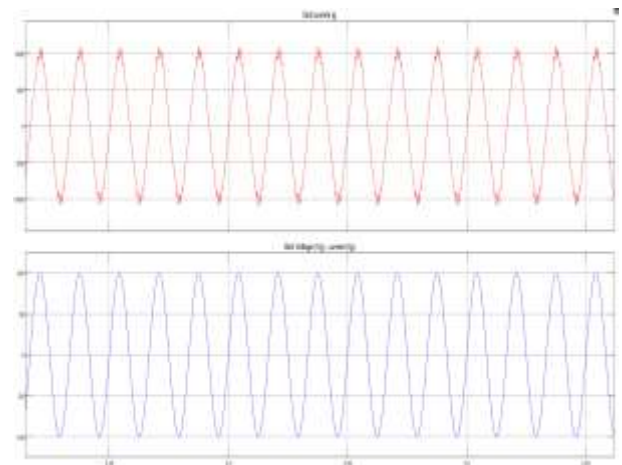


Fig 4. Grid current and grid voltage

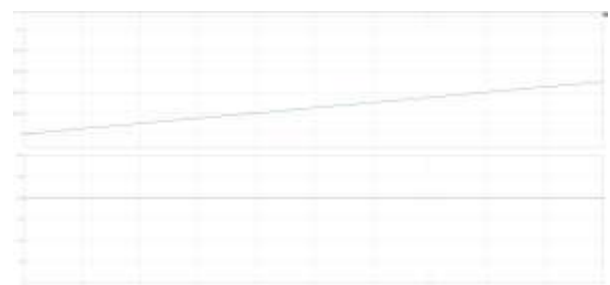


Fig 5. Battery SOC and voltage

Performance Analysis

Simulation studies were conducted under different battery voltage conditions.

The results demonstrate that:

- The charger maintains stable operation throughout the wide voltage range.
- Input current closely follows the supply voltage waveform.
- Near-unity power factor is achieved.
- Total harmonic distortion is significantly reduced.
- Fast transitions between CC and CV charging modes are observed.
- Adaptive fuzzy control improves transient response and robustness.

Comparative Analysis

Performance Metric	PI Controller	Conventional FLC	Proposed AFLC
Settling Time	High	Moderate	Low
Power Factor	0.94	0.97	0.99
THD (%)	6.5	3.8	2.1
Efficiency (%)	92.4	94.6	96.8

Adaptability Low Moderate High

Voltage Regulation Moderate Good Excellent

Advantages of the Proposed System

- Elimination of bridge rectifier conduction losses.
- Wide output voltage capability.
- Improved charging efficiency.
- Enhanced power quality performance.
- Reduced harmonic distortion.
- Near-unity power factor operation.
- Intelligent adaptation to varying charging conditions.
- Compatibility with multiple battery technologies.

IX. CONCLUSION

This paper presented an Adaptive Fuzzy Logic Controller-based universal bridgeless charger for wide voltage battery charging applications. The proposed charger successfully combines the efficiency advantages of bridgeless converter topologies with the intelligent decision-making capability of adaptive fuzzy control. Simulation results confirmed improved charging efficiency, superior dynamic performance, enhanced

voltage regulation, and significant reductions in input current harmonics. The charger demonstrated reliable operation across a broad battery voltage range without requiring controller retuning. Therefore, the proposed approach represents an effective and flexible charging solution for future electric vehicle and energy storage applications.

X. REFERENCES

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