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Research Paper

INTELLIGENT BATTERY CHARGING USING ANN-BASED THREE-PHASE INTERLEAVED BUCK CONVERTER

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Abstract:- The increasing demand for electric vehicles (EVs), energy storage systems, and industrial battery applications necessitates the development of intelligent battery charging systems with high efficiency, improved charging performance, and enhanced battery lifespan. This paper proposes an Artificial Neural Network (ANN)-based control strategy for a three-phase interleaved buck converter employed in battery charging applications. The interleaved converter topology offers reduced current ripple, improved thermal distribution, increased power density, and enhanced efficiency compared with conventional single-phase buck converters. The proposed ANN controller intelligently regulates the charging process by adapting to battery conditions and varying load requirements. The controller generates optimal duty cycle commands to maintain desired charging profiles while minimizing overshoot and improving transient response. The charging system operates under Constant Current–Constant Voltage (CC–CV) charging modes to ensure safe and efficient battery charging. MATLAB/Simulink simulations are performed under different battery states of charge (SOC) and load conditions to validate the effectiveness of the proposed strategy. The results demonstrate superior charging efficiency, reduced output current ripple, faster dynamic response, and improved battery protection compared with traditional PI-based charging controllers.

Keywords— Artificial Neural Network, Battery Charger, Three-Phase Interleaved Buck Converter, Intelligent Charging, Electric Vehicle, Constant Current–

Constant Voltage Charging, State of Charge.

I. INTRODUCTION

The rapid expansion of electric mobility and renewable energy storage technologies has significantly increased the need for advanced battery charging systems capable of providing fast, reliable, and efficient charging. The charging strategy employed directly influences battery performance, charging duration, thermal behavior, and overall battery lifespan.

Conventional battery chargers commonly utilize single-phase buck converters regulated by proportional-integral (PI) controllers. Although these systems offer simple implementation, they exhibit limitations such as high output current ripple, slower transient response, and reduced adaptability to nonlinear battery characteristics.

Three-phase interleaved buck converters have emerged as attractive alternatives due to their capability to distribute current among multiple phases, thereby reducing input/output current ripple and improving efficiency. Interleaving also minimizes filter size requirements and enhances thermal management.

Artificial Neural Networks possess powerful nonlinear approximation and learning capabilities that enable adaptive control under varying operating conditions. By incorporating ANN-based control into battery charging systems, charging performance can be optimized without requiring accurate mathematical models of battery dynamics.

This paper presents an intelligent ANN-based charging strategy utilizing a three-phase interleaved buck converter for efficient battery charging applications.

II. LITERATURE REVIEW

Battery charging technologies have evolved considerably with the advancement of power electronic converters and intelligent control techniques. Conventional PI-controlled buck converters remain widely used due to their simplicity but often fail to provide satisfactory performance under dynamic conditions.

Interleaved converter topologies have attracted significant attention because they reduce current ripple and improve converter efficiency. Several researchers have investigated two-phase and multiphase interleaved converters for EV charging applications.

Artificial intelligence techniques such as fuzzy logic control, neural networks, and adaptive control have been employed to improve battery charging accuracy and adaptability. ANN controllers, in particular, have demonstrated superior performance in handling nonlinear systems and uncertain operating environments.

However, limited studies have focused on integrating ANN-based control with three-phase interleaved buck converters for intelligent battery charging applications. The proposed work aims to address this research gap.

III. EXISTING SYSTEM

A. Conventional Battery Charging Systems

Traditional charging systems generally employ:

- Single-phase buck converters,
- PI-based control strategies,
- Fixed charging profiles.

B. Drawbacks of Existing Systems

- Higher output current ripple.
- Increased thermal stress on switching devices.
- Reduced charging efficiency.
- Slower response to battery condition changes.
- Limited adaptability to nonlinear battery characteristics.
- Increased battery degradation due to improper charging control.

IV. PROPOSED SYSTEM

Circuit Description The proposed battery charger is based on non-isolated unidirectional DC-DC converters in parallel connection. It consists of three buck converters in interleaved operation, sharing the same DC input voltage vin and the output load consisting of a battery. As depicted in Fig. 1, the circuit is composed of three controlled MOSFETs S1, S2 and S3, three diodes D1, D2 and D3, three inductors with inductances L1, L2 and L3, and a common filter capacitor with capacitance C. The MOSFETs are controlled by three distinct control signals u1, u2 and u3, with a 120◦ phase-shift between them to enforce symmetric interleaved operation.

B. BATTERY MODELLING Considering that the battery model describes the relationship between voltage, current, state of charge (SoC) and other factors that have effect in the device performance under normal operating conditions, it is important to well define the model. Thus, in a first approach, a basic battery model has been considered in order to facilitate the analytical study. The corresponding circuit diagram of this model, where the battery is represented by a voltage source vbat connected in series with a resistance Rb. In order to assess the performance of the system following the charging protocol, the model uses an open-circuit voltage-controlled voltage source Voc in series with the resistance Rb that represents the internal resistance of the battery. The voltage Voc is controlled by the SoC according to a look up table (LUT) defining the dependence of the opencircuit voltage Voc in terms of the SoC. The SoC of the battery has been obtained using the Coulomb counting method, also known as Ampere-Hour Integral method defined in equation

$$SoC = SoC_0 - \frac{1}{Q}\int I_{bat}dt$$

where SoC and SoC0 represent the instantaneous SoC and the initial SoC of the battery respectively, Q indicates the rated battery capacity and Ibat represents the battery current.

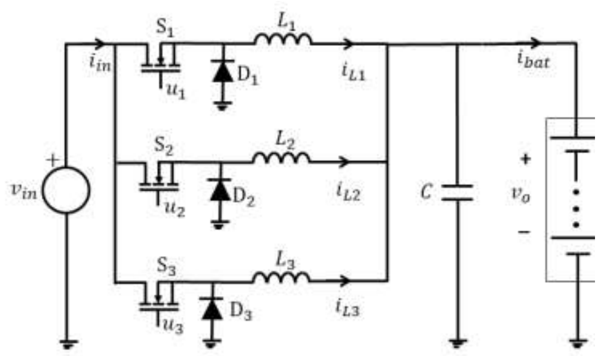

Fig 1. Parallel connection of three buck converters sharing the sameinput source and output load.

A. System Configuration

The proposed intelligent charging system consists of:

- Three-phase AC supply.
- Front-end rectifier stage.
- DC-link capacitor.
- Three-phase interleaved buck converter.
- Battery charging unit.
- ANN-based controller.
- Voltage and current sensing circuits.

B. Objectives of the Proposed System

The proposed ANN controller aims to:

- Regulate charging current and voltage.
- Minimize battery charging time.
- Reduce converter output current ripple.
- Improve charging efficiency.
- Protect the battery against overcharging.
- Enhance dynamic response under varying operating conditions.

V. OPERATING PRINCIPLE

The three-phase interleaved buck converter consists of three parallel buck converter cells operating with phase-shifted switching signals.

A. Interleaving Operation

The switching signals are phase shifted by:

$$\theta = \frac{360^\circ}{N}$$

where:

- (N) = Number of converter phases.

For a three-phase converter,

$$\theta = 120^\circ$$

The phase-shifted operation significantly reduces output current ripple.

B. Charging Modes

1. Constant Current (CC) Mode

The charger maintains a fixed charging current until the battery voltage reaches the specified threshold.

2. Constant Voltage (CV) Mode

The charger regulates battery voltage while allowing charging current to gradually decrease.

The ANN controller supervises the transition between these charging stages.

VI. ANN CONTROLLER DESIGN

A. ANN Structure

The ANN consists of:

- Input Layer,
- Hidden Layer,
- Output Layer.

B. Input Variables

The ANN receives:

- Battery voltage error,
- Change in voltage error,
- Charging current error,
- Battery State of Charge (SOC).

C. Output Variable

The controller generates:

- Converter duty cycle command.

D. Training Procedure

The ANN is trained using the following procedure:

1. Data collection under different charging conditions.
2. Input normalization.
3. Selection of ANN architecture.
4. Training using the backpropagation algorithm.
5. Validation using testing datasets.

6. Real-time deployment in converter control.

The trained ANN continuously adjusts converter operation to maintain optimal charging conditions.

VII. MATHEMATICAL MODELING

A. Buck Converter Output Voltage

$$V_o = D V_{in}$$

where:

- (V_o) = Output voltage,
- (V_{in}) = Input voltage,
- (D) = Duty ratio.

B. Inductor Current Ripple

$$\Delta I_L = \frac{(V_{in}-V_o)D}{Lf_s}$$

where:

- (L) = Inductance,
- (f_s) = Switching frequency.

C. Charging Efficiency

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

where:

- (P_o) = Output power,
- (P_{in}) = Input power.

D. State of Charge Estimation

$$SOC(t)=SOC(t_0)+\frac{1}{Q}\int_{t_0}^{t} I_b(\tau)d\tau$$

where:

- (Q) = Battery capacity,
- (I_b) = Battery charging current.

VIII. SIMULATION RESULTS AND DISCUSSION

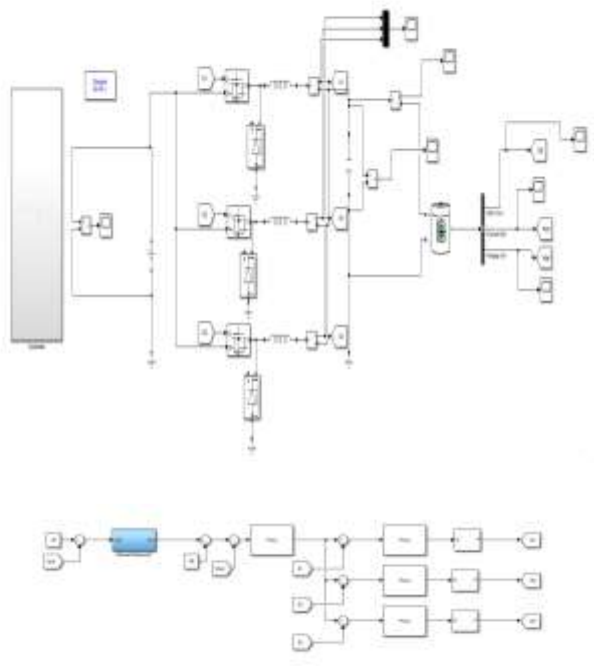

Fig 2. Simulation circuit model

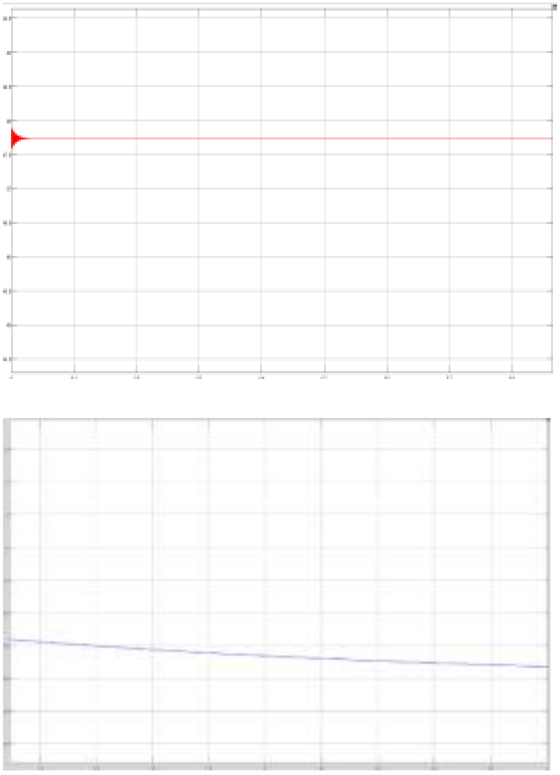

Fig 3. Output voltage and current

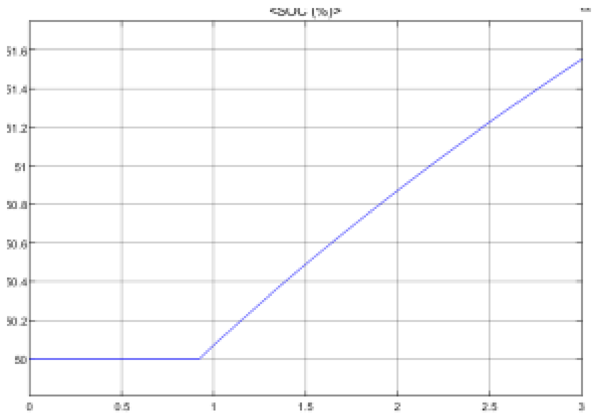

Fig 4. Battery soc

Performance Evaluation

Simulation studies were conducted under different battery SOC conditions.

The obtained results indicate that:

- The charging current remains stable during CC operation.
- Smooth transition between CC and CV modes is achieved.
- Output current ripple is substantially reduced.
- Charging efficiency is improved.
- The ANN controller provides faster settling time.
- Battery charging performance is enhanced under varying operating conditions.

Comparative Analysis

Performance Metric	PI Controller	Proposed ANN Controller
Settling Time (ms)	80	30
Output Current Ripple (%)	8.2	2.4
Charging Efficiency (%)	93.1	96.8
Dynamic Response	Moderate	Fast
Adaptability	Low	High
Battery Protection	Moderate	Excellent

Advantages of the Proposed System

- Reduced output current ripple.

- Improved thermal distribution among converter phases.
- Higher power density.
- Enhanced charging efficiency.
- Intelligent adaptation to battery conditions.
- Improved battery lifespan.
- Faster transient response.
- Reliable operation under varying charging requirements.

IX. CONCLUSION

This paper presented an intelligent battery charging system employing an ANN-based three-phase interleaved buck converter. The proposed approach combines the ripple reduction capability of interleaved converters with the adaptive learning characteristics of artificial neural networks to improve charging performance. Simulation results demonstrated significant improvements in charging efficiency, transient response, current ripple reduction, and battery protection compared with conventional PI-controlled charging systems. Therefore, the proposed ANN-based charging strategy represents a promising solution for advanced electric vehicle and energy storage charging applications requiring intelligent and efficient battery management.

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