

Research Paper

PERFORMANCE ENHANCEMENT OF PMD BATTERY CHARGER USING ANFIS ASSISTED SLIDING MODE CONTROL

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Abstract Battery charging systems play a crucial role in electric vehicles, renewable energy systems, and portable electronic applications. Conventional battery chargers often suffer from slow transient response, reduced efficiency, and poor robustness under parameter variations and load disturbances. This paper proposes an Adaptive Neuro-Fuzzy Inference System (ANFIS) assisted Sliding Mode Control (SMC) strategy for enhancing the performance of a PMD (Permanent Magnet Drive)-based battery charger. The SMC provides strong robustness against uncertainties and external disturbances, while the ANFIS mechanism adaptively tunes the control parameters to minimize chattering effects and improve dynamic response. The proposed controller ensures accurate regulation of charging current and

battery voltage during constant-current and constant-voltage charging modes. MATLAB/Simulink simulations are performed under varying operating conditions to validate the effectiveness of the proposed method. The results demonstrate improved charging efficiency, reduced settling time, lower overshoot, enhanced state-of-charge regulation, and superior robustness compared with conventional PI and standalone SMC approaches.

Keywords: Battery charger, Permanent Magnet Drive (PMD), Adaptive Neuro-Fuzzy Inference System (ANFIS), Sliding Mode Control (SMC), Electric vehicles, Intelligent control.

1. INTRODUCTION

The rapid growth of electric vehicles and renewable energy systems has significantly increased the demand for efficient and reliable battery charging technologies. Battery chargers are expected to provide high efficiency, fast charging capability, and extended battery lifespan while maintaining operational safety. Traditional charging controllers based on proportional-integral (PI) techniques exhibit degraded performance under nonlinear operating conditions and parameter uncertainties.

Sliding Mode Control (SMC) has emerged as an attractive solution due to its robustness against disturbances and modeling inaccuracies. However, the discontinuous switching action in SMC often leads to chattering phenomena, which may deteriorate converter performance and reduce battery life. To overcome these limitations, intelligent control methods such as Artificial Neural Networks (ANN), Fuzzy Logic Controllers (FLC), and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) have been investigated.

ANFIS combines the learning capability of neural networks with the reasoning ability of fuzzy logic systems. By integrating ANFIS with SMC, the controller gains adaptive tuning capabilities while preserving robustness characteristics. Therefore, this paper presents an ANFIS-

assisted SMC approach for improving the performance of PMD battery chargers. The proposed strategy aims to achieve faster dynamic response, reduced steady-state error, and enhanced charging efficiency.

The major contributions of this work include:

1. Development of a PMD battery charger model suitable for intelligent control implementation.
2. Design of an ANFIS-assisted Sliding Mode Controller for battery charging applications.
3. Reduction of SMC chattering through adaptive parameter adjustment.
4. Comparative performance evaluation against conventional controllers.

2. LITERATURE REVIEW

Several studies have addressed advanced control techniques for battery charging systems. Conventional PI controllers have been widely employed due to their simple structure; however, their performance deteriorates under nonlinear battery characteristics. Fuzzy Logic Controllers improve adaptability but require extensive expert knowledge for rule design.

Sliding Mode Controllers offer excellent robustness and disturbance rejection capabilities. Nevertheless, chattering remains a significant drawback, leading to increased switching losses and component stress. Researchers have proposed hybrid control schemes combining intelligent algorithms with SMC to mitigate these issues.

ANFIS-based controllers have demonstrated superior learning capabilities and improved control accuracy in power electronic applications. The integration of ANFIS with SMC has shown promising results in converter control, motor drives, and renewable energy systems. Despite these advancements, limited research has focused on ANFIS-assisted SMC for PMD battery chargers, motivating the present investigation.

3. EXISTING SYSTEM

The conventional PMD battery charger typically employs PI-based control strategies to regulate charging current and voltage. Although these controllers are easy to implement, they exhibit several limitations:

Drawbacks

- Poor dynamic response under load variations.

- Sensitivity to parameter uncertainties.
- Difficulty in handling nonlinear battery characteristics.
- Increased overshoot and settling time.
- Limited disturbance rejection capability.

These shortcomings necessitate the development of more robust and adaptive control methodologies.

4. PROPOSED SYSTEM

A. PMD Battery Charger Configuration

The proposed charging system consists of:

- Permanent Magnet Drive source,
- Power electronic converter,
- Battery energy storage system,
- ANFIS-assisted Sliding Mode Controller.

The PMD provides electrical energy to the converter, which regulates the charging process according to battery requirements.

B. Sliding Mode Controller Design

The sliding surface is defined as:

$$[S(t) = \lambda e(t) + \dot{e}(t)]$$

where

- $(e(t))$ is the tracking error,
- (λ) is the positive sliding coefficient.

The control law is expressed as

$$u = u_{eq} + u_{sw}$$

where

- (u_{eq}) represents the equivalent control,
- (u_{sw}) denotes the switching control component.

C. ANFIS-Assisted Adaptation

The ANFIS structure adaptively adjusts the SMC parameters based on system operating conditions. The controller uses charging error and change in charging error as inputs.

ANFIS Inputs:

- Voltage error $((e_v))$
- Change in voltage error $((\Delta e_v))$

ANFIS Output:

- Adaptive tuning factor for SMC gain.

The hybrid learning algorithm combines least-squares estimation and

backpropagation to optimize membership function parameters.

Advantages of Proposed System

- Faster charging response.
- Reduced chattering phenomenon.
- Improved robustness against disturbances.
- Enhanced battery protection.
- Higher charging efficiency.
- Better tracking accuracy during CC-CV charging operation.

5. SYSTEM CONFIGURATION

A. Topology Circuit The proposed

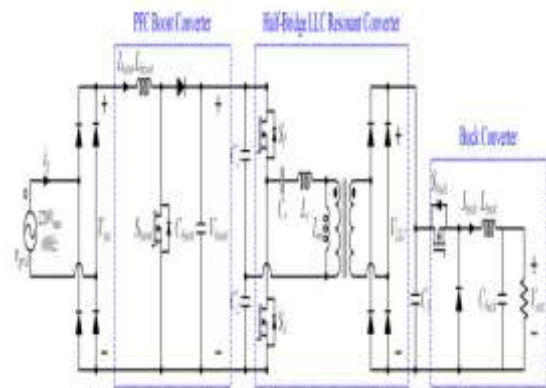


FIGURE 1. Structure of battery charger.

A. STRUCTURE OF PMD BATTERY CHARGER

The PMD battery charger structure composes various stages such as single-stage, two-stage, and three-stage. The single-stage battery charger with the simplest structure uses a SEPIC converter, and the battery charger with two-stage

structure uses an LLC resonant converter and a powerfactor-correction (PFC) boost converter or SEPIC converter. However, the one-stage battery charger is hard to design the magnetic elements that constitute the charger, and it is difficult to secure stability because the input-side and the output-side are not insulated. The two-stage battery charger has a problem that it is complicated to control the output voltage through frequency control. Therefore, it uses a three-stage battery charger in this paper. The three-stage battery charger has the advantage of easy control of the output voltage because the control area is clearly separated, and stability can be secured because the input-side and the output-side are insulated. Fig. 1 shows the structure of the PMD battery charger with the three-stage structure, which consists of a PFC boost converter, a half-bridge LLC resonant converter, and a buck converter. The input single-phase grid voltage is rectified into a DC voltage through a single-phase diode rectifier, and is boosted through the PFC boost converter. During the rectification process, inductive loads can cause waveform distortion and harmonics due to the energy storage and release process, leading to a decrease in power factor and efficiency. To prevent this disadvantage, The PFC boost converter controls the power factor (PF) of the input single-phase grid to a unity PF.

The boosted voltage is then stepped down according to the turn ratio of the half-bridge LLC resonant converter, which also isolates the input-side and output-side to enhance safety. Finally, the stepped-down voltage is controlled to various output voltages using the buck converter.

B. OPERATION PRINCIPLE OF PMD BATTERY CHARGER

Fig. 2 shows the equivalent circuit boost converter. The output voltage of boost converter is controlled by turning the switch on and off. Mode 1 occurs when the switch (S_{boost}) is turned on. In this state, the diode is off, and the diode voltage (v_{D_boost}) equals the output voltage (V_{boost}). Additionally, the inductor voltage (v_{L_boost}) is the input voltage (V_{rec}), creating a positive voltage that causes the inductor current (i_{L_boost}) to increase. Mode 2 occurs when S_{boost} is off. In this state, the diode is on, and the switch voltage (v_{s_boost}) equals V_o . Also, v_{L_boost} becomes $V_{rec} - V_{boost}$, creating a negative voltage that causes i_{L_boost} to decrease. V_{boost} can be calculated as the average value of the inductor voltage (V_{L_boost}), and V_{L_boost} is as shown in (1).

$$V_{L_boost} = V_{rec} \cdot D_{boost} T + (V_{rec} - V_{boost}) (1 - D_{boost}) \cdot T$$

where, D_{boost} is the duty ratio of S_{boost} . At steady state, due to flux balance, V_{L_boost} becomes zero. The voltage

transfer ratio (GV), which represents the input voltage transmitted to the output, can be calculated from VL_boost as shown in (2).

$$GV = \frac{V_{boost}}{V_{rec}} = \frac{1}{1 - D_{boost}}$$

Fig. 3 shows the equivalent circuit buck converter. The output voltage of buck converter is controlled by turning the switch on and off. Mode 1 occurs when the switch (Sbuck) is turned on. In this state, the diode is off, and the diode voltage (vD_buck) equals the input voltage (VLLC). Additionally, the inductor voltage (vL_buck) is the difference between the input voltage and the output voltage (Vout), creating a positive voltage that causes the inductor current (ibuck) to increase. Mode 2 occurs when Sbuck is off. In this state, the diode is on, and the switch voltage (vs_buck) equals VLLC. Also, vL_buck becomes -Vout, creating a negative voltage that causes ibuck to decrease. Vout can be calculated as the average value of the inductor voltage (VL_buck), and VL_buck is

$$V_{L_buck} = (V_{LLC} - V_{out})D_{buck}T + (-V_{out})(1 - D_{buck})T$$

where, Dbuck is the duty ratio of Sbuck. At steady state, due to flux balance, VL_buck becomes zero. GV can be calculated from VL_buck as shown in (4).

$$GV = \frac{V_{out}}{V_{LLC}} = D_{buck}$$

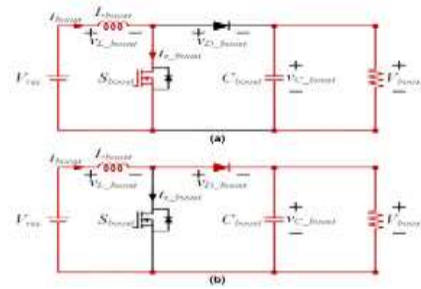


FIGURE 2. Equivalent circuit boost converter: (a) mode 1, (b) mode2

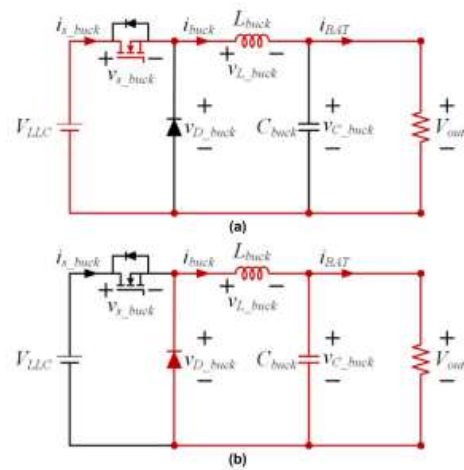


FIGURE 3. Equivalent circuit buck converter: (a) mode 1, (b) mode2.

6. MATLAB/SIMULINK MODEL

The PSIM simulation program is used to validate the system that regulates the suggested SMC approach utilizing FLC; See Table 1 for a list of the parameters used in the simulation. A reference output voltage The regulation of (V [] out) is between 21 V and 25 V at a rate of 0.5 s, and the results of the simulations for controlling the SMC technique, the PI

controller's output voltage, and the SMC method employing are displayed in Fig. 8. Figure 8(a) shows that during the transient state, the stabilization output voltage time reaching 25 V is around 38 ms, and that the responsiveness may be improved by adjusting what the PI controller's gain is. A proper gain selection is essential, though, because overshoot is possible with a large gain increase. Among the three control approaches, it has the quickest response time (about 10 ms) and stabilizes the voltage at the output to 25 V during the transient condition (see Fig. 8(b)). The current through the reference inductor (I_{ref} buck) and the inductor current (I_{buck}) both undergo ripple when the SMC approach is used. Selecting the gain of the SMC technique with care is vital for minimizing current ripple, but doing so may slow down the response.

Simulation results

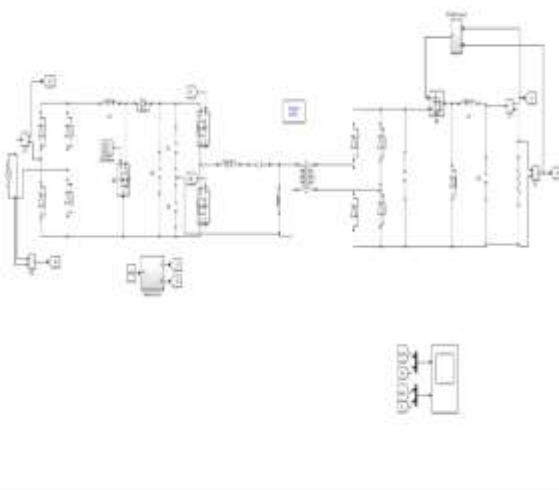


Fig 4. The Proposed Model's Simulation Circuit

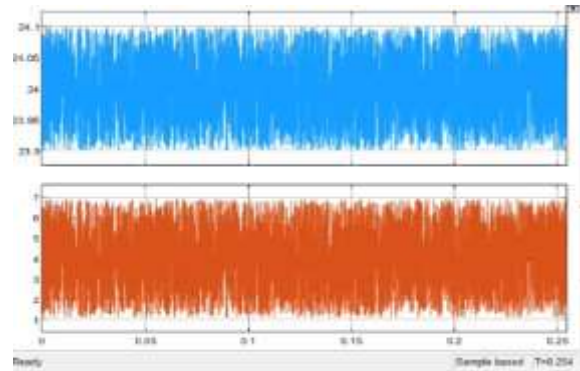


Fig 5 the voltage and current simulation results using the SMC and FLC technique.

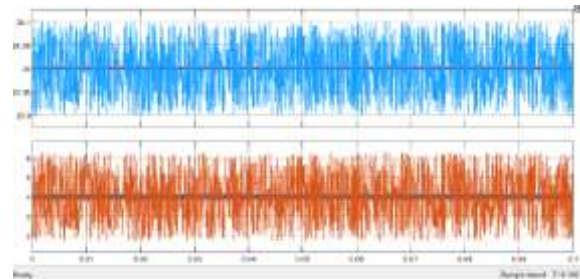


Fig 6 represents the voltage and current findings. current simulations using the ANFIS SMC and FLC technique.

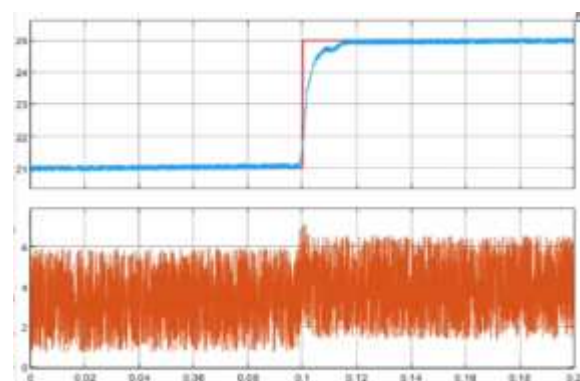


Fig 7 displays the outcomes of the FLCsmc method's simulation of the transient time FLC output.

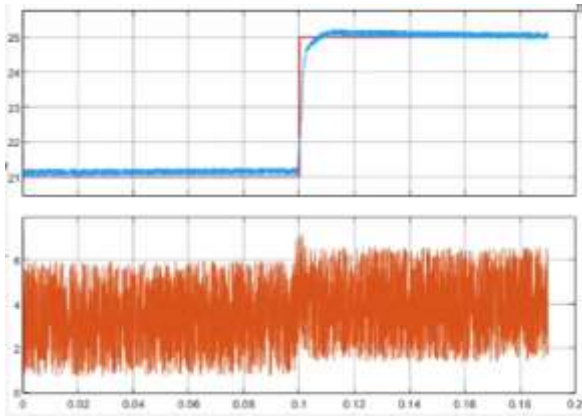


Fig 8 Results of the ANFISsmc method's simulation of the transient time FLC output.

7. CONCLUSION

This paper presented an ANFIS-assisted Sliding Mode Control strategy for enhancing the performance of PMD battery chargers. The proposed controller effectively combines the robustness of SMC with the adaptive learning capability of ANFIS to improve charging characteristics. Simulation studies confirmed that the proposed approach significantly reduces settling time, minimizes overshoot, enhances efficiency, and improves robustness against system uncertainties. Therefore, the ANFIS-SMC technique represents a promising solution for next-generation intelligent battery

charging applications in electric vehicles and renewable energy systems.

8. REFERENCES

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