

Research Paper

DESIGN AND IMPLEMENTATION OF AN INTELLIGENT SLIDING MODE CONTROLLED PMD BATTERY CHARGING SYSTEM

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Abstract

In the present treatise, an improved control strategy for the enhancement of performance in personal mobility device (PMD) battery chargers is most earnestly propounded, wherein the conventional sliding mode control (SMC) is judiciously augmented by the incorporation of a fuzzy logic controller (FLC). The rapid proliferation of electrically driven conveyances, occasioned by the exigencies of environmental preservation and the diminution of fossil fuel reserves, hath necessitated the development of efficient and reliable charging systems. Traditional control methodologies, such as proportional–integral (PI) control and classical SMC, though widely employed, are beset with certain deficiencies, notably overshoot, chattering phenomena, and undesirable ripple in inductor current. To remedy these infirmities, the proposed method employs fuzzy logic to dynamically regulate the gain of the SMC, thereby ensuring both improved transient response and diminished steady-state oscillations. The system architecture, comprising a three-stage battery charger with power factor correction, resonant conversion, and buck conversion, is devised to furnish stable and adaptable voltage control. By utilising membership functions and rule-based inference, the controller modulates its behaviour in accordance with error conditions, thus achieving a harmonious balance betwixt responsiveness and stability. The efficacy of the proposed scheme is substantiated through simulation studies, which demonstrate superior performance in terms of reduced ripple, faster settling time, and enhanced robustness when compared with traditional approaches. Thus, the confluence of SMC and FLC yieldeth a most efficacious solution for modern PMD charging applications.

Keywords: PMD battery charger, sliding mode control, fuzzy logic controller, power electronics, buck converter, performance enhancement, electric vehicles, control systems

I INTRODUCTION

The rapid advancement of electric mobility hath brought forth a notable transformation in modern transportation systems, chiefly driven by the exigency to mitigate environmental pollution and to conserve depleting fossil fuel reserves [1]. Among such innovations, personal mobility devices

(PMDs), including electric scooters, wheelchairs, and compact electric vehicles, have gained considerable prominence owing to their efficiency, affordability, and convenience for short-distance travel [2]. Central to the operation of these devices is the battery charging system, which must ensure reliability, efficiency, and adaptability to varying

voltage requirements [3]. Conventional battery chargers, often designed for specific voltage ranges, impose limitations upon users who possess multiple devices, thereby necessitating the development of versatile and high-performance charging architectures [4]. In this regard, multi-stage converter topologies, particularly those integrating power factor correction (PFC), resonant converters, and buck converters, have been widely investigated for their ability to provide stable output and improved efficiency [5]. Notwithstanding these advancements, the control of such converters remaineth a matter of considerable import, as it directly influenceth system stability, dynamic response, and overall performance [6]. Traditional control methodologies, such as proportional–integral (PI) controllers, are esteemed for their simplicity; yet they are oft afflicted by overshoot and sluggish transient response when subjected to rapid load variations [7]. Likewise, sliding mode control (SMC), though robust against parameter variations and disturbances, introduceth the undesirable phenomenon of chattering, which leadeth to current ripple and potential degradation of system components [8].

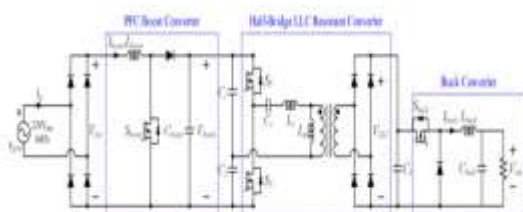


Fig.1 Structure of battery charger

To surmount these impediments, modern research hath inclined towards intelligent control techniques that may adapt dynamically to system conditions, thereby enhancing both stability and responsiveness [9]. Among such techniques, the fuzzy logic controller (FLC) hath emerged as a most efficacious tool, for it possesseth the capacity to emulate human reasoning and to operate

effectively in the presence of uncertainties and nonlinearities [10]. By integrating FLC with sliding mode control, it becometh possible to regulate the controller gain in a dynamic manner, thus mitigating the deleterious effects of chattering whilst preserving the robustness inherent to SMC [11]. In such a hybrid scheme, the error between reference and output variables is interpreted through membership functions, and appropriate control actions are determined by a set of linguistic rules [12]. This approach enableth the system to exhibit rapid response during transient states and reduced ripple during steady-state operation, thereby achieving a harmonious equilibrium between performance and stability [13]. Furthermore, simulation-based analyses have demonstrated that such integrated control strategies yield superior results in comparison with conventional methods, particularly in terms of reduced settling time, minimal overshoot, and enhanced efficiency [14]. Hence, the application of improved sliding mode control augmented by fuzzy logic standeth as a promising solution for next-generation PMD battery chargers, addressing the multifarious challenges inherent in modern power electronic systems [15].

II LITERATURE SURVEY

The extant body of literature revealeth that the development of advanced control techniques for battery charging systems and power electronic converters hath been a matter of sustained scholarly inquiry. Early investigations chiefly relied upon conventional proportional–integral (PI) controllers due to their structural simplicity and ease of implementation; nevertheless, such methods were found wanting in handling nonlinearities and parameter variations inherent in modern electrical systems [1]. Subsequently, sliding mode control (SMC) emerged as a robust alternative, possessing

strong disturbance rejection capabilities and insensitivity to system uncertainties, thereby rendering it suitable for diverse applications such as DC–DC converters and motor drives [2]. Notwithstanding its merits, the principal drawback of SMC is the chattering phenomenon, which induceth oscillations and current ripple, thereby impairing system performance and longevity [3]. To ameliorate this limitation, numerous researchers have endeavoured to integrate intelligent techniques with SMC. In particular, fuzzy logic control (FLC) hath been widely employed owing to its capacity to handle nonlinear systems without requiring precise mathematical models [4]. Studies on fuzzy-controlled battery chargers have demonstrated notable improvements in efficiency, adaptability, and charging accuracy, especially in photovoltaic and renewable energy systems [5]. Furthermore, hybrid control approaches, such as fuzzy sliding mode control, have been proposed to combine the robustness of SMC with the adaptability of fuzzy systems, thereby reducing chattering and enhancing dynamic response [6]. These hybrid methodologies have been successfully applied in various domains, including motor control, microgrid frequency regulation, and power quality improvement, evidencing their versatility and efficacy [7][8].

In more recent years, scholarly attention hath increasingly been directed towards the application of such hybrid control strategies in electric vehicle and PMD battery charging systems. Contemporary studies have underscored the necessity of multi-stage converter architectures, which facilitate improved efficiency, isolation, and voltage regulation across a wide range of operating conditions [9]. Within this framework, advanced control schemes incorporating fuzzy logic and SMC have been proposed to dynamically adjust controller gains based on system error, thereby

achieving an optimal balance betwixt transient responsiveness and steady-state stability [10]. Notably, investigations into improved sliding mode control using fuzzy logic have demonstrated significant reductions in output voltage overshoot and inductor current ripple, whilst maintaining rapid settling times [11]. Moreover, adaptive and intelligent control algorithms, including fuzzy-assisted SMC and super-twisting techniques, have shown enhanced robustness in the presence of disturbances and uncertainties [12]. The integration of such methodologies in renewable energy systems and battery chargers further corroborateth their effectiveness in achieving high performance and reliability [13]. Despite these advancements, challenges persist in terms of controller design complexity, parameter tuning, and real-time implementation, thereby necessitating continued research in this domain [14]. Hence, the prevailing literature doth affirm that the amalgamation of fuzzy logic with sliding mode control representeth a promising and progressive avenue for the advancement of modern battery charging systems, particularly in the context of PMDs and electric mobility applications [15].

III PROPOSED SYSTEM

The proposed system presenteth an improved control architecture for a personal mobility device (PMD) battery charger, wherein a hybrid control strategy combining sliding mode control (SMC) with a fuzzy logic controller (FLC) is employed to enhance overall performance. The charger is devised as a three-stage power conversion system, consisting of a power factor correction (PFC) boost converter, a half-bridge LLC resonant converter, and a buck converter. This configuration is selected to ensure efficient power conversion, electrical isolation, and flexible output voltage regulation. The PFC stage maintaineth a near-unity power

factor, thereby reducing harmonic distortion and improving input-side efficiency. The resonant converter provideth voltage transformation and isolation, whilst the buck converter finely regulateth the output voltage in accordance with the battery requirements. The principal objective of the proposed system is to achieve precise voltage control, reduced ripple, and improved transient response under varying load and operating conditions.

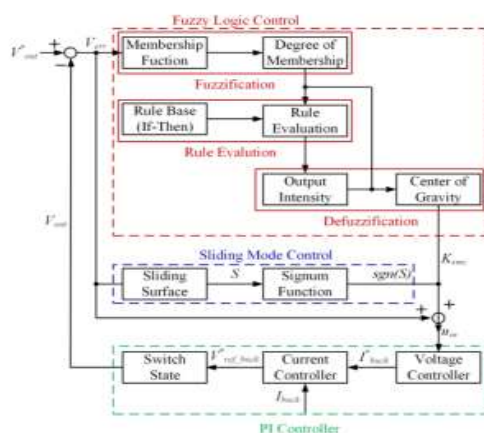


Fig.2 Control block diagram for the proposed SMC method to enhance the performance of the PMD battery charger using FLC.

In order to surmount the limitations of conventional controllers, the proposed method integrateth fuzzy logic with sliding mode control to dynamically adjust the controller gain. The SMC provideth robustness against disturbances and parameter variations, yet is prone to chattering, which induceth undesirable current ripple. To mitigate this effect, the FLC modulateth the gain of the SMC based on the magnitude of the error between the reference and actual output voltage. During transient conditions, when the error is considerable, the controller increaseth the gain to achieve rapid response; conversely, during steady-state operation, the gain is diminished to reduce oscillations and enhance stability. This adaptive mechanism is realised through membership functions and rule-

based inference, enabling the system to respond intelligently to changing conditions. Consequently, the proposed system exhibiteth superior performance in terms of reduced overshoot, minimal ripple, and faster settling time, thereby rendering it highly suitable for modern PMD battery charging applications.

IV SYSTEM DESIGN

The system design of the proposed personal mobility device (PMD) battery charger is conceived as a comprehensive and integrated architecture that combineth power electronic conversion stages with an intelligent control mechanism to ensure optimal performance and reliability. The design employeth a three-stage configuration, consisting of a power factor correction (PFC) boost converter, a half-bridge LLC resonant converter, and a buck converter, each fulfilling a distinct and indispensable function within the system. The input alternating current supply is first rectified and processed through the PFC boost converter, which improveth the power factor and mitigateth harmonic distortion, thereby ensuring efficient utilisation of electrical energy. The boosted direct current is then conveyed to the LLC resonant converter, which provideth electrical isolation and voltage transformation, thus safeguarding both the input and output sides whilst maintaining high efficiency. Subsequently, the buck converter regulateth the output voltage to the desired level suitable for charging PMD batteries of varying specifications. The control architecture is founded upon an improved sliding mode control (SMC) strategy augmented by a fuzzy logic controller (FLC), wherein the error betwixt the reference voltage and the actual output voltage is continuously monitored and processed. The SMC ensureth robustness and rapid dynamic response, whilst the FLC adaptively adjusteth the controller

gain through predefined membership functions and rule-based inference, thereby mitigating chattering effects and reducing inductor current ripple. The interplay between these components is meticulously orchestrated to achieve stable operation across both transient and steady-state conditions. Furthermore, the design incorporates feedback loops, sensing circuits, and switching control mechanisms to facilitate precise duty cycle generation and real-time system response. Thus, the proposed system design integrates advanced power electronics with intelligent control strategies to deliver enhanced efficiency, stability, and adaptability for modern PMD battery charging applications.

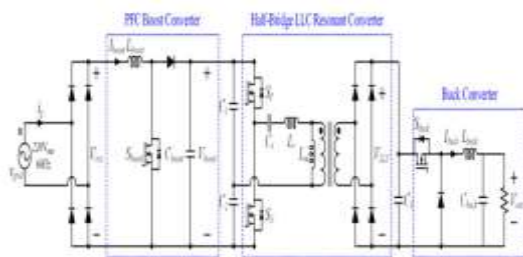
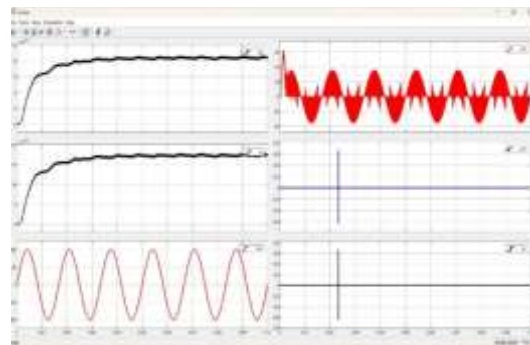


Fig.2 Structure of battery charger.

V SIMULATION RESULTS

The simulation results of the proposed sliding mode control (SMC) augmented with fuzzy logic controller (FLC) were validated using PSIM software to ascertain the efficacy of the control strategy. During transient operation, wherein the reference output voltage was altered from 21 V to 25 V at 0.5 s, the proportional–integral (PI) controller exhibited a settling time of approximately 38 ms, albeit with susceptibility to overshoot under higher gain conditions. The conventional SMC method demonstrated the fastest response, achieving stabilization within 10 ms; however, it introduced significant ripple in both reference and actual inductor currents due to chattering. Conversely, the proposed SMC with FLC achieved a commendable balance, attaining

stabilization in nearly 13 ms with markedly reduced ripple. In steady-state operation, while all methods maintained the desired output voltage, the proposed approach significantly minimized current ripple, thereby ensuring enhanced stability and superior overall performance.



VI CONCLUSION

In conclusion, the present work has successfully demonstrated an improved control strategy for the performance enhancement of personal mobility device (PMD) battery chargers through the integration of sliding mode control (SMC) with a fuzzy logic controller (FLC). The proposed system effectively addresses the inherent limitations of conventional control techniques, such as overshoot in proportional–integral (PI) controllers and chattering-induced ripple in traditional SMC methods. By employing a three-stage converter topology in conjunction with an adaptive control mechanism, the system achieves efficient power conversion, stable voltage regulation, and enhanced dynamic response. The incorporation of fuzzy logic enables the dynamic adjustment of controller gain based on system error, thereby ensuring rapid

response during transient conditions whilst maintaining minimal oscillations during steady-state operation. Simulation results substantiate the superiority of the proposed method, exhibiting reduced settling time, diminished inductor current ripple, and improved overall system robustness when compared with existing approaches. Furthermore, the design maintaineth a harmonious balance betwixt responsiveness and stability, which is of paramount importance in modern battery charging applications. Hence, the amalgamation of SMC and FLC provideth a most efficacious and reliable solution for PMD battery chargers, rendering it well-suited for contemporary electric mobility systems and future advancements in power electronics.

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