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Performance Enhancement of Three-Port EV On-Board Chargers through Partial Power Processing and SMC

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Abstract
Electric vehicle (EV) on-board charging solutions that are small, efficient, and fast are in great demand due to the accelerated adoption of EVs. In order to provide dependable and efficient on-board rapid charging for electric vehicles, this study introduces a new design for partial power converters that incorporates Sliding Mode Control (SMC) into three ports. An additional energy storage device, such a secondary battery or supercapacitor, and the vehicle's battery may all transmit power to and from the grid at the same time under the suggested architecture, allowing for better energy management and dynamic power sharing. Total power losses are decreased, conversion efficiency is increased, and passive components may be downsized thanks to the system's use of a partial power processing technique. By providing better voltage regulation and rapid transient response than traditional control approaches such as PI or PWM-based schemes, the Sliding Mode Control technology guarantees resilient performance under parameter fluctuations and load disturbances. Verified by simulations, the suggested method works as intended, with improved power conversion efficiency and steady charging performance under varying loads. Because it combines small size, high efficiency, and intelligent management, this design suggests that next-generation electric vehicle on-board chargers will be available.

Keywords: *Electric Vehicle (EV), SMC, Partial Power Processing (PPP), fast charging, Three port converter (TPC).*

1. Introduction

The widespread adoption of electric vehicles (EVs) as a viable transportation option in the future has accelerated the push for rapid charging stations that can compete with the ease of filling up with traditional fossil fuels. Both the on-board as well as off-board chargers need to be built with more power to match this expectation of faster charging times. Unfortunately, when it comes to on-board charger setups, having a high power output usually means using more expensive and bulky AC-DC power conversion components, which in turn reduces efficiency. In addition, the charger's efficiency along with thermal performance are directly affected by the large power losses that occur at high output levels. The two-stage AC-DC conversion designs often used by EV chargers include a two-port buck-boost converter and a full power processing (FPP) DC-DC converter, as illustrated in Figure 1(a). The constant current-constant voltage (CC-CV) modes allow these systems to regulate and charge batteries by maintaining an intermediate bus voltage, such as 300 V. Nevertheless, the components in such setups are subjected to high voltage stress (400-600 V), which reduces their efficiency, increases thermal stress, and limits their scalability to greater power levels. Recent studies have investigated methods such as bidirectional converters, soft-switching, and high-gain single/two-stage designs to overcome these restrictions. Peak efficiencies remain restricted to 92%-96% with growing complexity of systems and

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component count, even with current advancements. The use of pricey digital controllers like dSpace in these systems is common, which increases the execution cost and design effort even further.

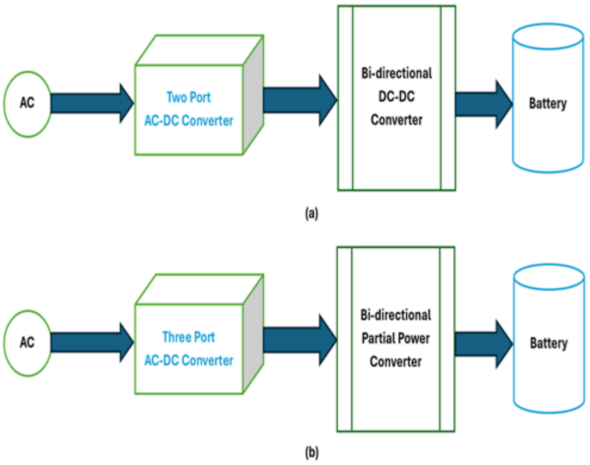

Figure 1 System architecture (a) The traditional charger that uses a two-port converter from FPP, and (b) the fast charger that is being suggested, which has three ports

In response to these issues, this investigation presents a new design for on-board rapid electric vehicle chargers that use PPP and incorporate SMC for improved dynamic performance and system resilience. Figure 1(b) shows that the suggested layout uses a bidirectional buck-boost PPP DC-DC converter after a three-port AC-DC boost converter. This setup minimizes the power evaluated by the DC-DC stage, which improves efficiency, reduces device stress, and decreases cost and space by transferring the bulk of the power straight to the battery through the three-port converter [1].

2. System Modelling

An essential component of this design, the SMC controller offers a very reliable method of controlling the PPP DC-DC stage and the three-port converter. In EV charging systems, where input/output fluctuations and parameter uncertainties are widespread, SMC guarantees quick transient response, disturbance rejection, and system stability—unlike traditional PI or linear controllers. To provide precise regulation of voltage and current throughout the charging cycle, SMC employs a nonlinear and discontinuous control action that successfully propels the system states onto the target sliding surface and keeps them there [2].

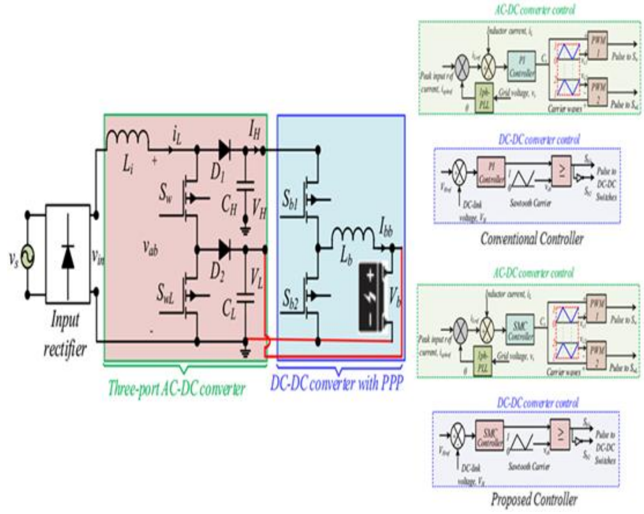

Figure 2 System Configuration with control (Conventional & Proposed)

Figure 2 shows the intended charging circuit, which includes an AC-DC converter with three ports for boost power at the front end and a bidirectional buck-boost DC-DC converter with partial power processing (PPP) thereafter. This three-port PPP charger with an SMC incorporated has several important benefits, such as: 1) The charger is more efficient since the DC-DC converter only handles a small percentage of the power, 2) Reduced voltage stress on the device throughout the three-port converter stage (VL and VH→VL), allowing for lower rated switches to operate at high power, 3) Partial power operation reduces DC-DC converter current stress, enabling small and inexpensive switch selection, 4) Sliding Mode Control provides a fast dynamic reaction and excellent resilience, surpassing PI and linear controllers in the face of parameter fluctuations and load disturbances, 5) Streamlined system implementation of embedded SMC, reducing complexity and expense by doing away with costly control hardware like dSpace. As shown in Table I, the proposed SMC-based PPP charger is compared to traditional FPP-based systems in great detail [3-8]. This proves without a reasonable doubt that the suggested method is the best option with regard to size, cost, control performance, and scalability Shown in Figure 3 - 10.

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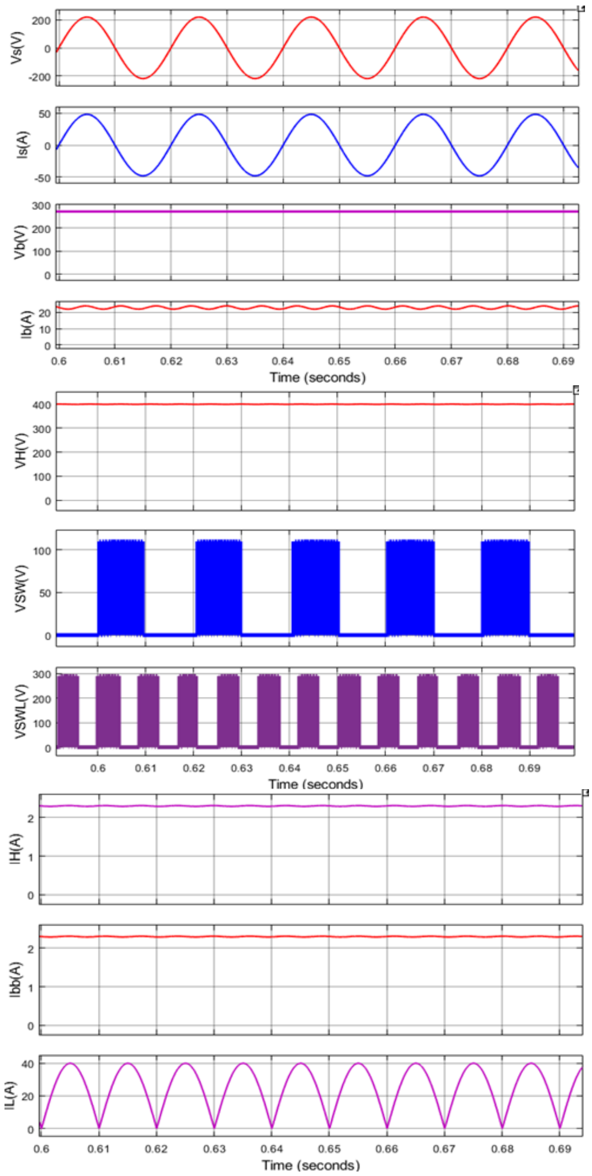
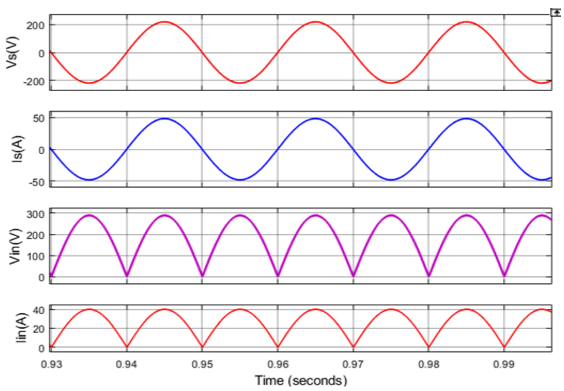
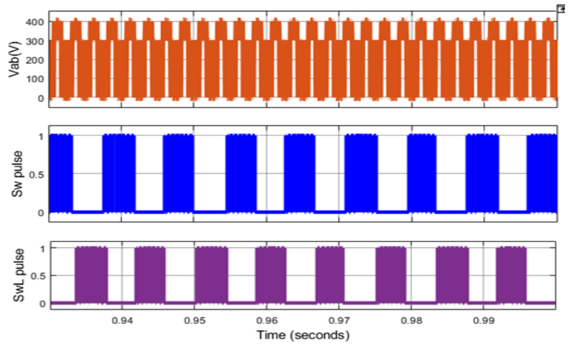
3. Results



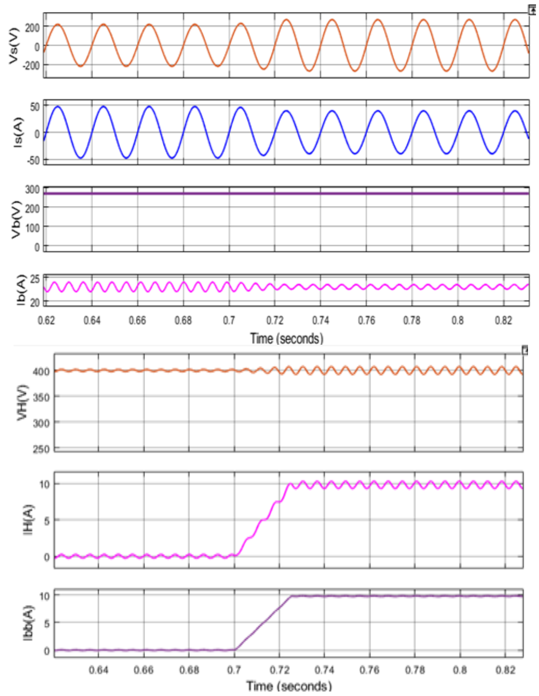
(a)



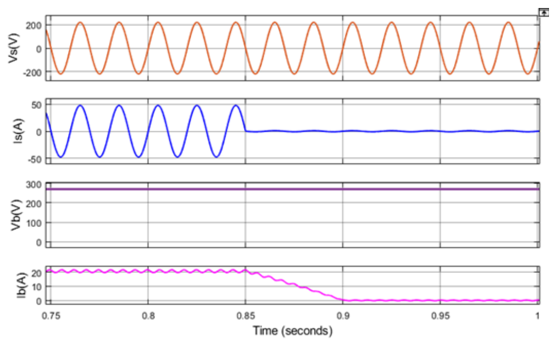


(b)

Figure 3 Simulated Performance of proposed fast charger during steady statecondition, showing waveforms of (a)input and output side quantities with switchvoltage, and (b) vin, iin and pole voltage, vab with respect to gate pulses to Swand SwL.



(a)



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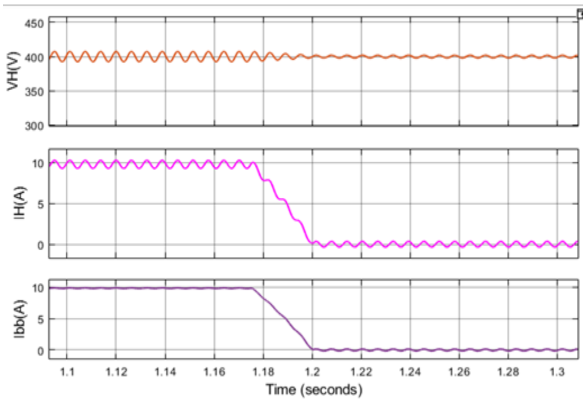
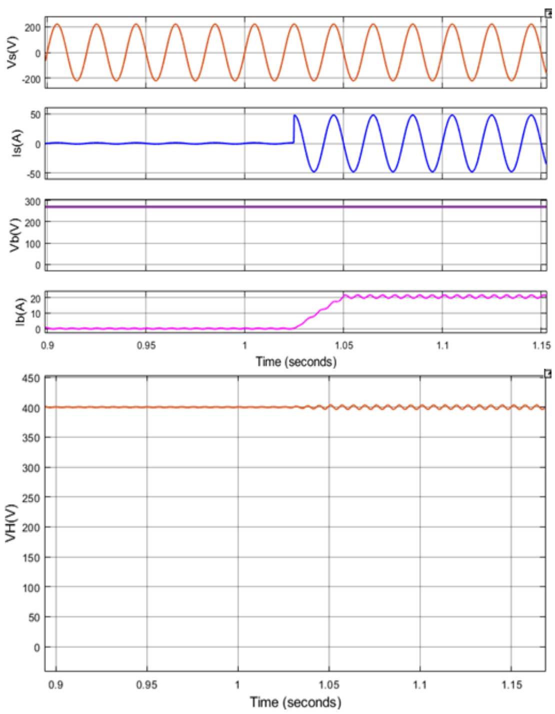
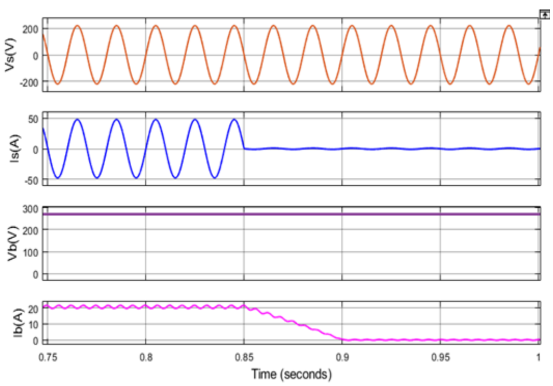


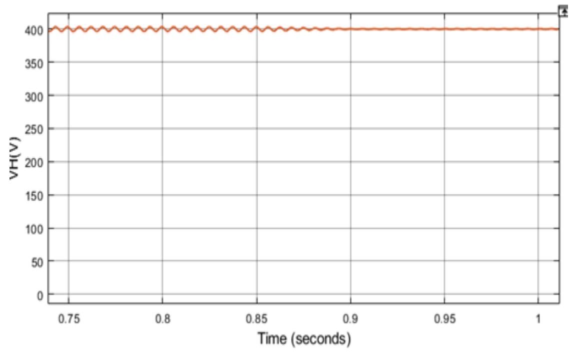
(b)

Figure 4 Simulated Performance of proposed fast charger during change in vs (a) from 220 V−270 V, and (b) from 270 V−220 V



(a)





(b)

Figure 5 Simulated performance of proposed fast charger during (a) startup condition, and (b) shut-down condition

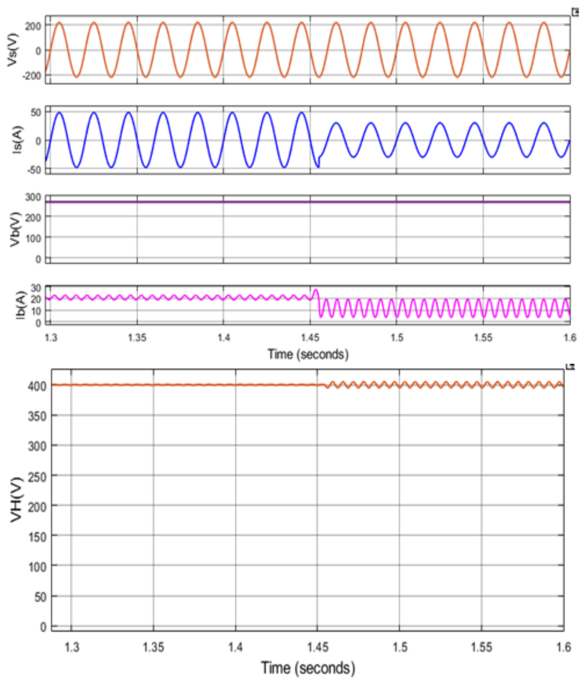
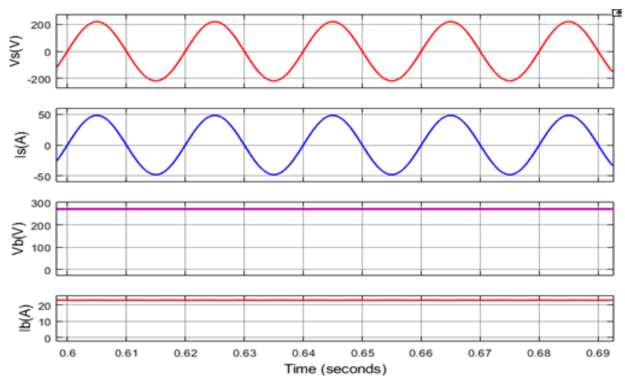


Figure 6 Simulated performance of proposed fast charger during change in load i.e., Ib changes from full load to half load



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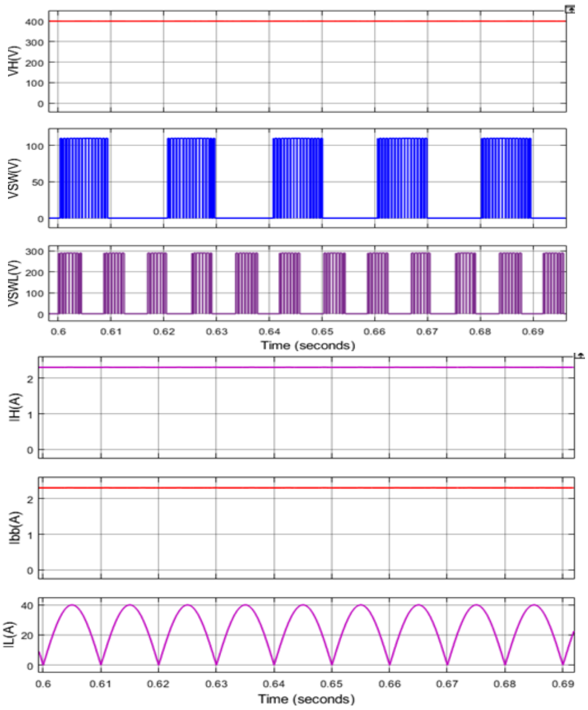
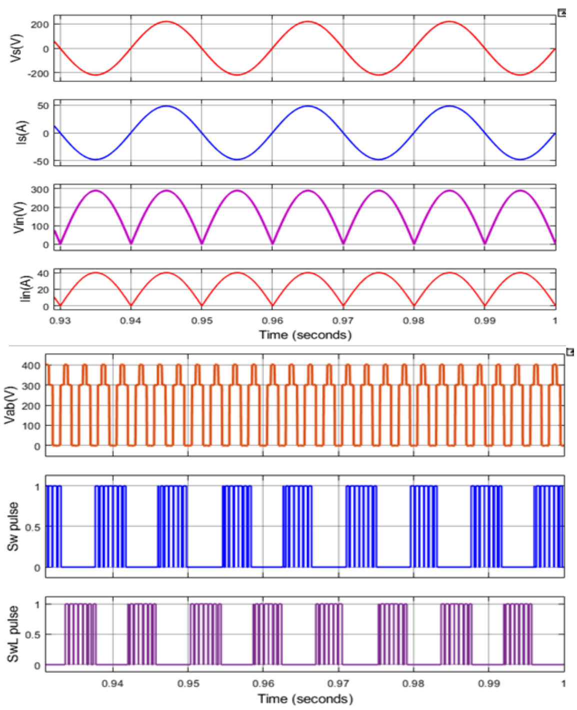
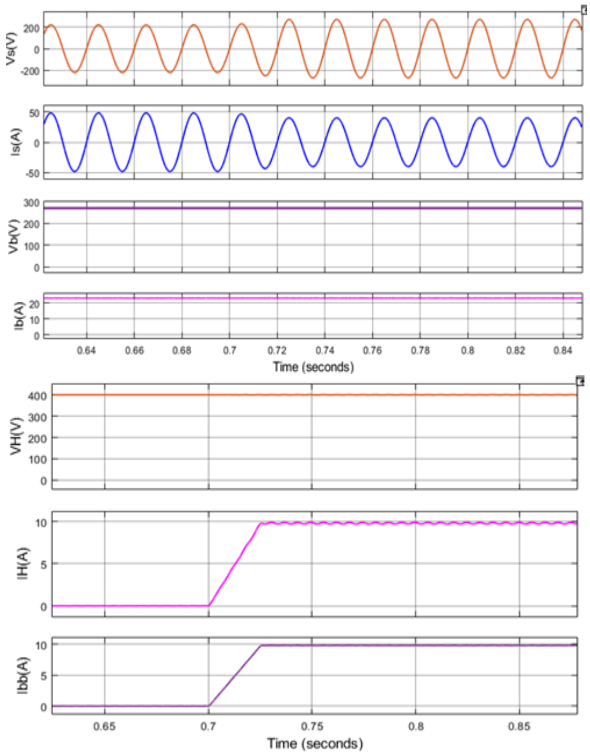


(a)

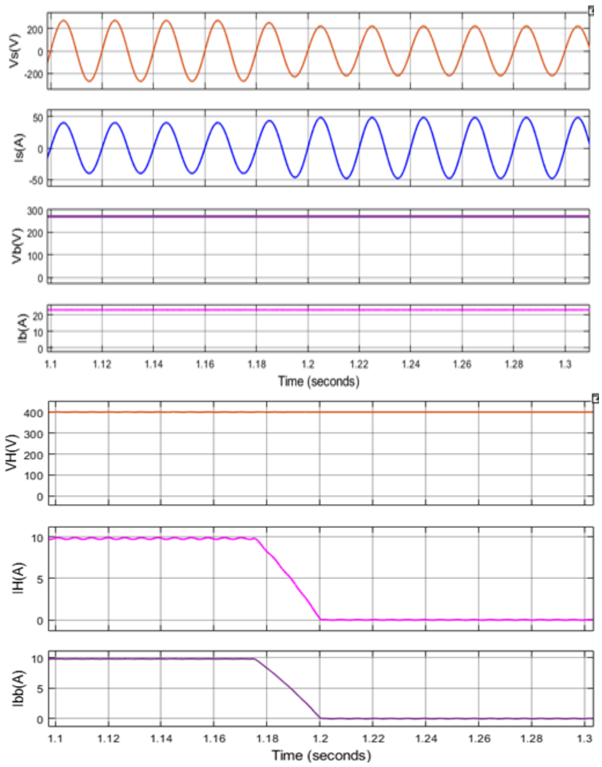


(b)

Figure 7 **Simulated Performance of proposed fast charger during steady statecondition, showing waveforms of (a)input and output side quantities with switchvoltage, and (b) vin, iin and pole voltage, vab with respect to gate pulses to Swand SwL**



(a)



(b)

Figure 8 **Simulated Performance of proposed fast charger during change in vs (a) from 220 V−270 V, and (b) from 270 V−220 V**

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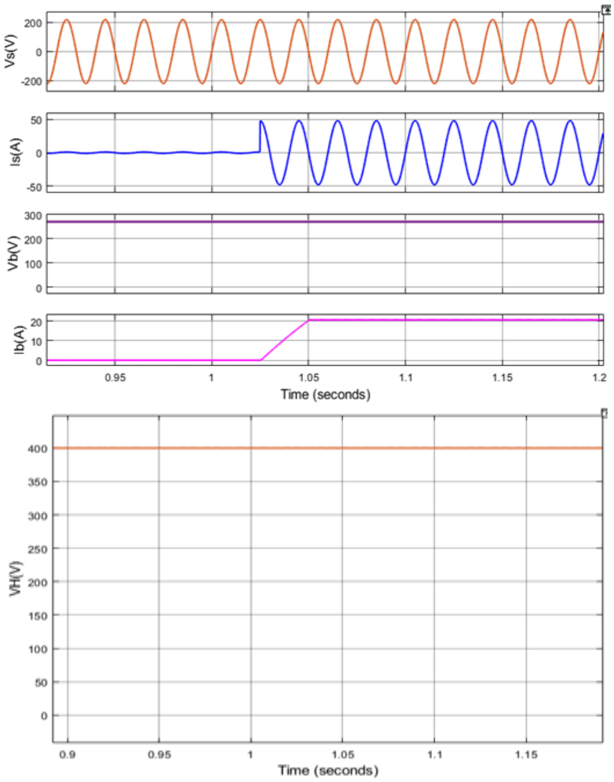
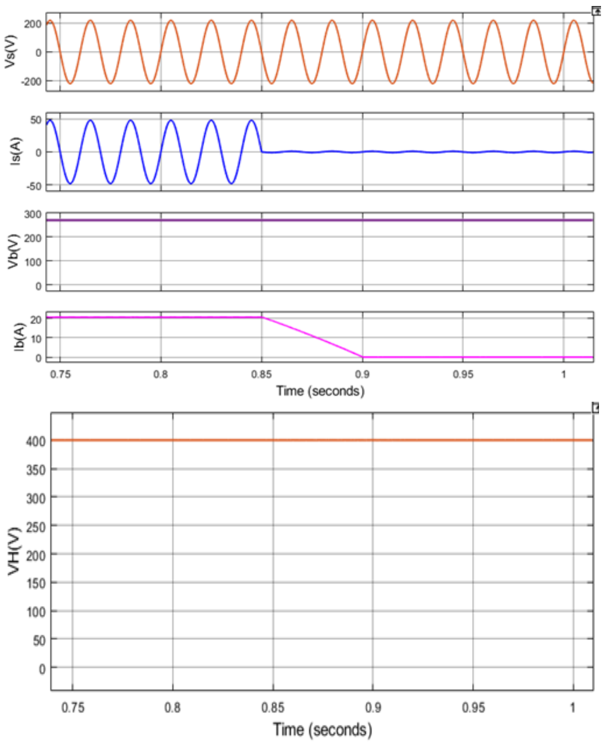


(a)



(b)

Figure 9 Simulated performance of proposed fast charger during (a) startup condition, and (b) shut-down condition

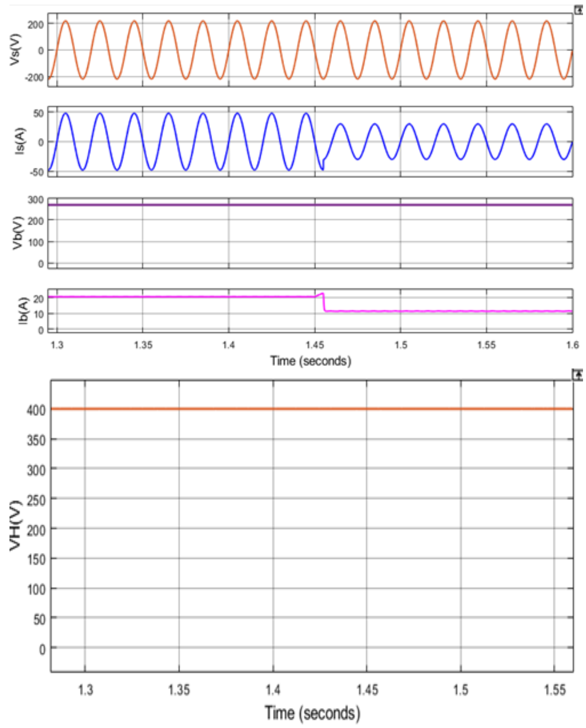


Figure 10 Simulated performance of proposed fast charger during change in load i.e., Ib changes from full load to half load

Conclusion

In order to improve control performance and system stability, this study introduces a new rapid charger configuration that uses aTPC-PPP and SMC. Reduced charger size, thermal losses, and system cost are the results of the suggested TPC-PPP architecture's successful mitigation of AC-DC stage device voltage stress and DC-DC stage current stress. Under the suggested setup, the front-end TPC handles the bulk of the power transfer from the grid to the battery, with the DC-DC converter handling just a small percentage, around 10%. This approach to partial power processing improves system efficiency and lowers converter rating in comparison to conventional FPP chargers. An impressively high peak efficiency of 96.13% was attained, even for a hard-switched topology. Increased charging speed without sacrificing system safety or power quality is a result of the SMC's effective management of the greater operational DC-link voltage. Future EV on-board rapid charging systems might benefit from the suggested SMC-based TPC-PPP charger's small size, low price, and excellent performance.

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